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Durability of Building Materials & Components 8

Service Life and Asset Management

VOLUME 4

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edited by
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and
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Michael A. Lacasse and Dana J. Vanier
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Preface

Asset managers are faced with many difficult decisions regarding when and how to maintain and repair their constructed facilities. The reasons behind these difficult decisions are the growing fiscal constraints, an increasing maintenance deficit and a substantial repair backlog. In addition, asset managers' resources are being challenged from all sides: they are also being asked to cut cost, privatise operations, outsource responsibilities, reduce maintenance and increase efficiency. These problems are exacerbated by the lack of: (1) usable data, (2) information and knowledge related to maintenance, (3) repair and service life prediction techniques, and (4) tools to assist the asset manager to make proper inspection, maintenance, repair and replacement choices.

Many of these problems would be solved if more information exchange were present in the construction industry regarding service life and asset management. Many organisations have in recent years recognised the scope of the problems facing asset managers. Unfortunately existing opportunities offer only partial solutions to many of the problems in asset management. Hence there is a pressing need for research and development in this field. For example: (1) what maintenance data are required to predict service life of materials and components, (2) what are the life cycle costs of maintenance and repair alternatives, (3) what techniques are available for service life prediction, (4) how can performance be quantified using objective and representative indicators (5) how can the likelihood of failure be calculated and the consequences of failure be identified, and finally, (6) how to integrate this information to allow asset managers to make cost-effective and objective decisions on maintenance, repair and renewal alternatives?

It is within this framework that the conference themes were chosen and to which many authors have provided significant contributions to the advancement of their respective research fields. The collected body of works, presented herein, focuses on topics related to integrating existing knowledge together with the more recent contributions on service life and durability of construction and building materials, components, and assemblies. Particular emphasis has been placed on information technologies in construction and its' role in integrating knowledge through classification schemes, product models, information retrieval systems and collating and dissemination technologies.

The proceedings have been published in four volumes. The first volume, "Service Life and Durability of Materials and Components" contains four parts each reflecting those contributions made to the durability of specific building materials, namely: concrete, masonry, wood, and polymers. Within the part on concrete materials, there are several sub-sections including service life prediction of concrete structures, strength and durability, corrosion, and papers on issues related to design and innovation. The second volume "Durability of Building Assemblies and Methods of Service Life Prediction", contains six parts, the first three of which provide those papers related to environmental characterization, building facades, and roofing materials and components. Within this last area, roofing maintenance management has likewise been included as this provides the collected works in the area of roofing as a distinct part of the proceedings. The final three parts of this volume focus on methods of service life prediction, including probabilistic and reliability methods, generic methods, and lastly, development and use of guides and standards. "Performance, Service Life Prediction and Sustainable Construction" is the third volume in which the collected works are presented in four parts, starting with maintenance management, and followed by life cycle costing and economics, performance and serviceability of buildings (CIB W060 workshop), and life cycle analysis and sustainable, durable design. The final volume "Information Technology in Construction", represents those papers submitted to theCIB W78 workshop of the same name and is prepared in eight sections including computer-integrated construction, the construction process, decision-support systems, design systems, life cycle models, product modeling, process modeling, and virtual reality.

Collectively these contributions provide a selected overview of approaches, methods, techniques, tools, systems and technology used to develop knowledge on the service life durability of construction and building materials, components and assemblies and the integration of this information towards asset management. As such, it is hoped the many whohave contributed to these proceedings, as well as those who in the future will partake in perusing its many pages, will gain in an understanding of the issues, a knowledge of the techniques, some insight into the research, and healthy discernment of useful technologies.

Finally, in editing the various papers and thereafter preparing them for final copy, the editors have made every effort to produce a faithful reflection of the authors' contributions based on their revised manuscripts. However, as might be expected in proceedings of this size, and irrespective of their many efforts, the editors concede that unfortunately, but ultimately, there are likely to be found errors and omissions. These we genuinely regret and would like to express in advance our apologies for any such oversights.

M.A. Lacasse and D.J. Vanier,
Editors, 8DBMC
Ottawa, 1999

Foreword

This conference represents the 8th triennial in a series, in which the previous seven were held in Ottawa (1978), Gaithersburg (1981), Espoo (1984), Singapore (1987), Brighton (1990),Omiya (1993), and Stockholm (1996). The evolution of these collected works over the past two decades attest to the persistent and incessant pursuit of knowledge on the durability of materials, components and assemblies whether in regards to fundamental or applied research, or the most recent technological innovations. These conference proceedings have been representative of the state-of-the-art on service life prediction methods and the durability of constructed facilities.

More recently, attention has been placed on deriving from these sources of information, a means of providing practitioners with ready access to the vast body of knowledge encompassed within studies on the "durability of materials". Moreover, recent advances in information technologies permit its use as an integration tool and dissemination device, and a suitable interface to the current and evolving needs of practitioners. It is in this context that the 8DBMC provides a unique venue for exhibiting the most recent innovations in information technologies as a tool to link various research fields associated with service life prediction.

Consequently, this set of conference proceedings focuses on topics related to integrating existing knowledge together with more recent contributions on service life and durability of construction and building materials, components and assemblies. This includes work in the area of service life prediction methods and modeling, field studies and evaluation methods, degradation mechanisms, material characterization, and other related items. It is also concerned with providing a forum for new knowledge in the area of service life directly related to life cycle economics, maintenance management, performance requirement modeling, probabilistic and reliability methods, as well as, promoting the integration of this knowledge towards practical applications with emphasis on the use of information technologies as an integration tool.

These proceedings will be of interest to construction researchers, practitioners and designers concerned with service life prediction and durability as well as asset mangers interested in obtaining knowledge about the most recent innovations currently being considered as management tools. Information technologists will find considerable scope towards the application side of their emerging technologies.

These volumes are therefore a singularly valuable set of documents and a worthy addition to the previous collected works and to the annals of the Institute for Research in Construction.

Sherif Barakat
Director General
Institute for Research in Construction
National Research Council Canada
Ottawa, 1999

Acknowledgements

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M.A. Lacasse and D.J. Vanier
Editors, 8DBMC
Ottawa, 1999

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KEYNOTE PAPERS

206 INFORMATION EXCHANGE ARCHITECTURES FOR BUILDING MODELS

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Abstract

The work in building product models, beyond the need to develop the appropriate semantics for representing building data, needs to address the information flow issues arising from the current procedures of architecture, engineering and construction practice. Offered here are four scenarios common to building practice and an analysis of the information flow issues arising from the need to support these scenarios. The issues arising from such studies are named Information Exchange Architectures. The study of Information Exchange Architectures is posed as an area requiring much study if data exchange technologies are to be used in everyday practice.

Keywords: STEP, data exchange, building models. process models

1 Introduction

A growing number of building product models have been developed that respond to information exchange needs in different aspects of the overall building life cycle. Here, I am referring to the ISO-STEP building models, including CIMsteel (CIMsteel 1993), Building Elements Using Explicit Shape Representation (Part 225 1996), Part 106, the Building Construction Core Model (BCCM 1996), COMBINE (Augenbroe 1995) and also the Industry Foundation Classes (IFC) (IAI 1997), which also used STEP implementation technologies. Most of these modeling efforts have focussed on the semantics of the data model itself. They have addressed many of the difficult issues of data modeling, such as the growing levels of detail that must be addressed throughout the design process, the need to dynamically associate packages of performance attributes with various objects, often at the instance level, in response

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to contextual performance issues. Overall, much progress has been made in developing practical solutions to the semantic structuring of building product models. A growing number of these building models are being used, especially CIMsteel and the IFC.

On the implementation side, most of these models rely on the STEP Standard Data Access Interface (SDAI) (Part 22 1993) that defines a code library that supports reading from and writing to a STEP part model. Almost all implementations rely on exchanges based on one application writing to a file and the second application reading from that file. This results in the following exchange scenario:

> *A user extracts from a building application the data in the application that is to be exchanged with another application. An interface to the application writes out the data according to an EXPRESS schema. That format is then interpreted by an interface to a second application that has been paired with the sending one. It extracts the data in the neutral format and loads it into second application, which can now be executed.*

For later reference, I call this the *Standard Exchange Scenario*. The Standard Exchange Scenario is very general and is defined in terms of data exchange, rather than information exchange. Yet I believe that this form of exchange has very limited use within the building life cycle. Effective sharing of building data requires that we support the *processes* in which data exchange is embedded. These processes involve possibly complex information exchanges, beyond the pairwise exchange between two models. We call these information flows and the environment that goes with them different *Information Exchange Architectures*.

Data exchange comes in all scales, from the exchange of a complete project to just a few variables. Flows may be linear or iterative. There are several dimensions of a data exchange architecture that are important to different building modeling contexts. In this paper, I review these different dimensions of data exchange because they pose important research questions that must be addressed if the significant work on building models is to be used productively.

These different dimensions can be illustrated by considering different scenarios involving information exchange in current building processes. There are many common scenarios. In the following section, four scenarios are presented that detail some of the information flows encountered in the building life cycle. They are imaginary, anticipating the time when there is growing use of diverse applications. Otherwise, they reflect current practices. The scenarios depict different issues arising in building model information exchange architectures. When we compare the requirements of these scenarios to the capabilities supported by the current technology, we can begin to identify the gaps in current data exchange technologies needed to support different building data exchange contexts.

After these scenarios, their aspects are considered and used to identify significant research issues needed in the area of Information Exchange Architectures.

2 Information exchange scenarios

2.1 Scenario one: Design coordination

An architectural firm's lead designer has laid out the schematics for a high rise office building. The firm's associates are working on the service core of the building, using a variety of applications. An initial layout of the service core was defined, which is now being refined by the design team members. One associate is detailing the restrooms, using a restroom design application, another the fire stairs using a stairwell application and another the elevators, using an application from an elevator manufacturer. In parallel, other designers are working on the facade, the lobby and other aspects of the building using various applications. As the designers modify and detail parts of the existing design, they coordinate with the other people being affected. This may involve a pairwise exchange ("can you give up three inches on the south wall of the restroom"?), or a group may form to determine the best solution to an issue based on their mutual perspectives (where to route plumbing lines). They collaborate on schedules ("I'll wait to detail the stairs since you are reconsidering the floor-to-floor height"). As changes are made, they are distributed to the other designers. If a change is proposed or made that cannot be accommodated by the others, then these are reviewed with the principal who adjudicates and resolves conflicts. This scenario is characterized in Figure 1.

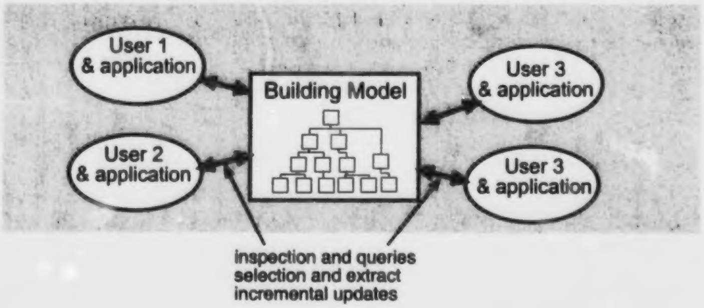

Fig. 1: A data exchange scenario between members of a single design team

In this scenario, the building data is treated as a repository that is shared, accessed and incrementally updated by the design team. Team members query the contents of the current design and select the information relevant for their tasks. Modifications are written back to the repository as incremental updates, changing or adding details. Updates made to shared data must be communicated to all whose work is affected. In general, participants need to know who has what data, so that coordination and the distribution of updates are facilitated. This scenario is very close to current practice, where all people are using a single CAD system. The main difference is that the designers are now using heterogeneous design tools.

2.2 Scenario two: Energy consultant advises on design

The architectural firm has employed an energy consultant, in part because the client is concerned about ecological issues. The consultant is to advise on energy efficiency and to assess environmental conditions throughout the building. During the review, she analyzes potential issues of glare, both from lighting and from the expanse of glass on the south and west facades (among other issues). For the glare issue, she examines the building layout and typical sky lighting intensity (using data gathered by herself for this city), the expected interior surface finishes, and internal lighting. Running the figures through a lighting analysis application, the exterior light coming in windows is found to be quite high and of high contrast with the internal lighting. After discussion with the architect, two alternatives are explored—using high levels of internal lighting to reduce contrast or reducing the external lighting level and relying more heavily on local light sources. The architect opts for the latter, and the consultant examines louvers, overhangs and external sunshades by assessing their behavior in lighting simulations. She identifies several alternatives for the architect to select from. He chooses to use exterior louvers integrated into the building facade. The architect revises the layout and passes it back to the consultant, who reruns the analyses and tries variations to enhance its benefits for certain days of the year. This scenario is diagrammed in Figure 2.

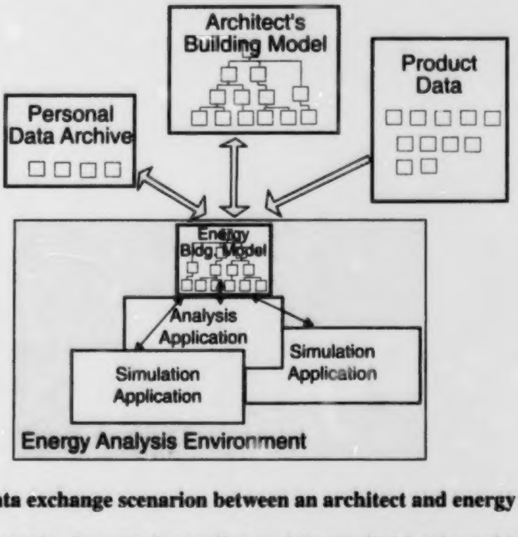

Fig. 2: The data exchange scenarion between an architect and energy consultant

In this scenario, the consultant relies on data supplied by the architect, but also retrieves data from a variety of other sources—weather information, her own data on sky conditions, material and finish properties and product information. She integrates the various data within her own modeling environment to support various simulations and analyses. Design alternatives are generated by both the consultant and architect, that are passed back and forth for analysis and possible design integration.

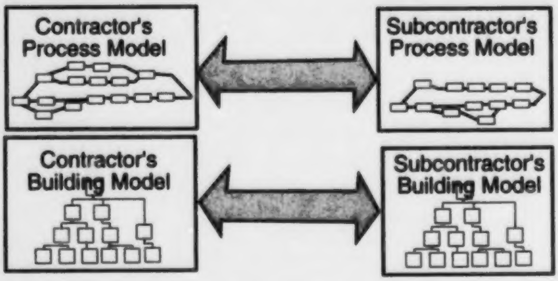
Contractor's Process Model
Subcontractor's Process Model
Contractor's Building Model
Subcontractor's Building Model

Fig. 3: The data exchange scenario between two contractors planning parts of the same job

2.3 Scenario three: Construction scheduling

A project manager for a general contractor is developing a very tight construction schedule for a large scale building project. In parallel, the sub-contractor for structural fabrication and erection is developing that company's schedule. In order to speed construction, the agreed to strategy is to begin finishing the lower floors while the upper level structure is still being erected. To do this, both organizations must closely coordinate. Week-by-week site and floor layouts have been printed to coordinate material stockpiling and the location of work assignments. Both groups proceed to develop their own detailed schedules independently, based upon an agreed to general schedule of structural erection and finishing. As both persons proceed, they communicate daily to resolve issues, assumptions about the other's work and to resolve differences.

In this scenario, two separate schedules are being planned, based on a shared high level schedule. Spatial conflicts, material and product specifications and task dependencies are checked, with conflicts identified and resolved during reviews.

2.4 Scenario four: Pass off of the construction model to the facility owner/manager

Here, the as-built design is passed from the contractor to the building owners/managers. The contractor has been paid to revise the architect's drawings, to reflect changes that were made during construction. The revised drawing files are then passed to the client organization, which uses a commercial facility management database to manage its facilities. After the revised drawing files are archived, another version is abstracted and simplified to obtain the general layout data required by the facility management package. Additional data is added, such as the enclosed spaces, organizational boundaries, HVAC control zones and other regions of relevance to facility management, but not represented in the original model. So that proper maintenance schedules can be planned for mechanical equipment, specifications from the mechanical equipment suppliers are added to the model. Equipment specifications are currently defined in paper manuals, but will eventually move to an electronic format. Materials used in public spaces are identified so that maintenance schedules for these spaces can be developed.

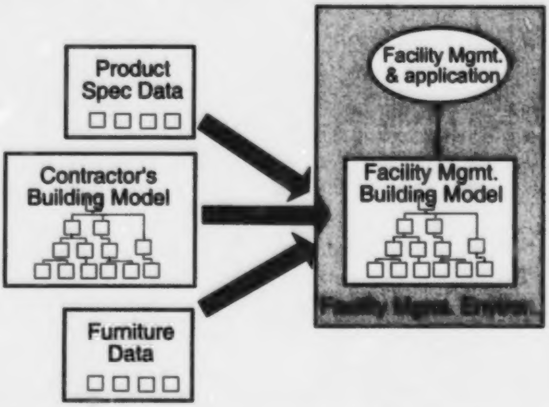
Product Spec Data
Contractor's Building Model
Furniture Data
Facility Mgmt. & application
Facility Mgmt. Building Model
Facility Mgmt. Environ.

Fig. 4: Data exchange scenario from contractor to facility manager

In this scenario, there is a single pass-off of data. The pass-off involves integration of data from heterogeneous sources—the equipment operating and maintenance manuals. The pass-off is done once for the total project, in one direction.

3 Data exchange architecture needs

These four information exchange scenarios are only a small sample of many different but common data exchanges regularly undertaken within any building project. The scenarios presented are not meant to be exotic, but rather typical of the kinds of task coordination that building models were meant to support.

Upon examination, however, these four scenarios have different information flows than that provided by the Standard Exchange Scenario, emphasized by the most STEP technology. By identifying these differences, we begin to articulate a new set of issues beyond information representation that needs to be addressed in the wider research on building models.

3.1 Batch exchange or repository with updates

The data flow provided by current exchange capabilities is that one application sends a dataset and the other one loads the result. The data is not in a repository that can be added to, modified or deleted by different applications, as depicted in Scenarios One, Two and Three. There is no mechanism for two or more datasets to be merged for input to a third application. A related issue is whether building model data may be generated by multiple applications instead of a single one. Scenarios Two and Four consist of a merging of several data sources, where the building model is only one source.

Batch exchanges are relatively straightforward. A dataset is prepared for exchange by the source application and user. It is received whole by one or more receiving applications. If a receiver carries earlier data describing the building, it is overwritten by the new data. Exchanges may be in either or both directions, but they are all-or-nothing—no partial updates are allowed.

If an application is to update an existing model or to merge data from different models, there must be some means to identify which entity instance is being updated or extended. Unambiguous object identification is required. A second issue is how to track those entities that have been changed, so other users of the changed data can be notified. Thus two additional functional capabilities are required if the building model is a repository that supports selective extraction and incremental updates.

(1) *unique identification*: Each object must have a unique identification, so that the repository copy of the object can be found and updated with a new copy, if necessary. The Integrated Resources of Part 043 and also the IAI Resource Layer generate such identifiers, which must be carried by the application. The requirement for unique identification also places a requirement on the application, because it must carry object identifiers that can be used in matching against those read from the repository.

This problem is made more complex when it is realized that building models carry data at different levels of aggregation. That is, suppose we update the description of a window. A model may aggregate information about the wall that includes the windows. It may carry higher levels of aggregation, such as a facade which is also defined in terms of properties of a window. Some properties of spaces—such as lighting level and HVAC loads—are also defined in terms of windows.

These other descriptions at different levels of aggregation were not defined initially by the building model itself, because they carry specialized information about design. Rather they were generated by applications. Thus one update implies that to complete the impact of the update the same application or other ones must update the model also. This is an issue of change management, taken up in issue number three below.

(2) *partial updates*: If only some of the objects in the repository are read and not others, bookkeeping must properly interpret the updates. If there are 40 walls on a floor and an application reads 25 of them, then after execution writes back 22 of them, what is implied for the 3 missing ones? A mechanism must be provided to distinguish additions and deletions, as well as modifications. If all the objects read by an application are flagged, those not written back can be assumed deleted by the application. If the application writes back new ones without IDs, these can be assumed to be new ones. Others that are both read and then written back with matching IDs are interpreted as updates. Some techniques for managing partial

updates have been reported in (Eastman, Jeng *et al.* 1997).

3.2 Data inspection and selection by the receiver

In current exchange capabilities, the dataset to be exchanged is prepared by the sender. The sender determines what the receiver will acquire. In the Standard Exchange Scenario, the receiver cannot directly inspect and select the data needed, but must communicate with the sender beforehand. Part of effective use of a building model used as a repository is that users can browse, query and select what portions of the building model are to be accessed and transferred to their application for use.

Browsing and querying of a building model need to support the traditional accessing mechanisms now provided by current CAD tools and standard database queries (Elmagarid 1992), but integrated in ways not provided by these systems alone (Jacobsen *et al.* 1997). Because of the diverse users and needs, multiple accessing structures are needed. Architects and other users, for example, usually review a building based on spatial access of the data, as presented by floorplans and other sections and spatial visualizations of the building. Building specification people review a building based on the classification structure of building specifications—the Construction Specification Institute (CSI) structure in the US— accessing entities that are part of a particular system or that have a particular function. Product suppliers and consultants today search a set of drawings by functional systems, such as by mechanical systems, lighting, or communication systems, so as to bid on them. There needs to be multiple ways to query a building model—no one capability is likely to be appropriate for the different interest groups.

Building models are typically very large, both in terms of the number of classes in the model, and also in terms of the number of instances carried within a dataset. They carry multiple redundant descriptions of some building or design part, needed for the different applications. Tracking through this structure without powerful query capabilities will not be acceptable.

The capabilities outlined here are not yet available in production form. However, aspects are provided by some products of STEP product vendors, such as those offered by STEP Tools Inc. and EPM Technology. These capabilities require both language extensions to support high level queries and also application development tools that include graphical user interfaces. More work needs to be done to develop such facilities, if building modeling is to be a ready-to-use production tool. While the 3D modeling of the Boeing 777 and other examples suggest that these capabilities are being developed in other fields and need only be adapted for use in building, the truth is more complicated. The visual modeling of the 777 was not tied to a workable database. In reality, the building industry is more concerned with large assemblies of 3D objects than most other fields. Product model interfaces with effective end-user browse and query mechanisms do not exist. They will be needed, however, if we expect effective use of building models.

3.3 Populating a model involving multiple sources

The data from a building model is often only one part of the information used in the development of another model. Particularly in the scenario of the energy analyst, the data regarding buildings, building products, users and local weather conditions are combined to define another model. From this perspective, building model data is only one of multiple types needed for most analysis applications. Input data extracted and reformatted from multiple sources is commonly required, resulting in a custom-configured dataset.

A simplified diagram of such an environment is shown in Figure 5. The figure illustrates that a building model is only one information source among several that are needed to support most building tasks. Most tasks require access to different data: specifications of installation procedures, building codes, engineering or design details, user data or programmatic requirements. The building information is only one part of the information support needed.

Many building-related Web browser technologies have shown the practical and effective use of general purpose search tools capable of operating on unstructured data. The implication is that text-based search engines, "rummaging" over Web sites and digital encoding of reference manuals and other information sources, could provide one type of effective means to access other kinds of data needed for building-related tasks. There is a growing business in developing special purpose Web sites for particular classes of users, such as architects, engineers and contractors. There are a number of efforts to use Web crawlers and other off-line search techniques to index Web sites of interest in a particular domain and provide them in a gateway site. Surely these technologies will all play a growing role in accessing data in the building industry and for populating data in domain or application specific building models.

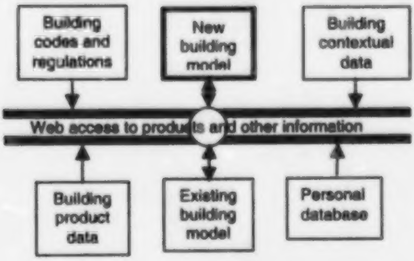

Fig. 5: Composition of models from many data sources

The basic structure of World Wide Web data is a simple encoding language called HyperText Markup Language (HTML). HTML supports text and graphic raster formats for transmission and display, using any Web viewing program, such as Netscape Navigator or Microsoft Explorer. The HTML language and HTML viewers also support plug-ins. These are add-on applications to the base viewers that support other encodings than those native to HTML. And HTML allows other formats to be encoded within it. Some of the useful plug-ins for building product use include:

Acrobat	-	book-quality formatted text and images in PDF format
Shockwave	-	dynamic, animated multimedia
!Whip	-	displays DWG files reformatted as DWF files, supports hyperlinks
Softsource	-	displays DWG and DWF files reformatted as SVF files, supports hyperlinks
Dr. DWG	-	displays and supports hyperlinks and redlining of DWG files
VRML (Virtual Reality Modeling Language)	-	3D models, with a real-time viewer
OliVR	-	real-time video with sound
Quicktime	-	real-time video with sound

A newer net format is Extensible Markup Language (XML). XML supports the development of custom formats and appears to have the capability of directly representing EXPRESS models. It will be worth watching the developments of XML as a future exchange language, especially for net-based data exchange (Doherty 1998; Goldfarb and Presod 1998).

This perspective suggests that building product model data, encoded in EXPRESS of other format, should be available in the same way that all the above kinds of information are available through a standard Web browser. Some CAD companies have recognized this direction and have embedded browsers into their CAD system environment. Some of the software companies selling EXPRESS tools include HTML and XML related capabilities. This promising direction is just being initiated and is likely to have a major impact in the future.

However, how is all this data structured and composed? How does it get composed into a building model? Ideally, one can "dream" of a grab and drop interface, allowing selection and transfer from various Web sites to a building model. No tools allowing such exchanges exist today. Who will help to create them?

3.4 Single view model or multiple views

Existing exchange capabilities emphasize a single, neutral model for holding building information. However, Scenarios Two and Three point out the regular use of multiple, parallel but disjoint models in architectural and construction practice. The scenarios illustrate a simple truth: given current building industry practices, it will not be common in the foreseeable future to have a single repository that captures all the information used in building design, in construction, or in building operation. Even within a single stage, multiple data models are likely to co-exist, given current business practices and the information needs of different engineering domains. The different actors, for both technical and professional reasons, do not fully integrate their results into a single dataset.

The use of multiple models to represent a product is also the premise adopted by the ISO-STEP organization in their development of application protocols. Application models, as defined in the STEP architecture, are the same as what are called aspect models here. If different aspect models, such as CIMsteel, COMBINE and Part 225, were all used in the same project, some data carried in each aspect model would be shared and other data would be closely related. There would be a need to coordinate and possibly run evaluations on the data within pairs of models, or across all three. The coordination may be carried out in several ways:

- to use one model to initialize the other two
- to update a change made in one model so that the other two are consistent with it
- or to check that the three models are consistent with each other by applying a third model to resolve conflicts in their data

With multiple models, two particular sources of inconsistencies arise. One source are the computations during the mapping from one representation to another. When done manually, mapping errors are common. However, mappings can be largely automated, as we shall see. The other source of inconsistency results from incorrect propagation of changes between representations. An example is that, in the mechanical design, a boiler is relocated, but its structural load and location are not updated and checked by the structural package. An automatic mechanism is needed to check that the source entities and target entities of all internal maps are consistent. If they are not, then the map must be re-executed. Of course, which map to re-execute and the propagation of this update to others requires wider consideration.

A major emerging line of work in the product modeling community deals with the derivation of views and with mapping between different product models. The need for view generation results when one or more applications require data that involves complex derivations from the base product model. Instead of putting these derivations into external translators to/from the application, the model can serve a wider set of needs by embedding them in the model and the resulting exchanges can be more transparent and robust (Bailey 1996). A related need is to map model instance data between one product model and another, when the two models incorporate common information. These needs have resulted in the development of mapping languages (Verhoef *et al* 1995). Two pieces of work are particularly relevant here. EXPRESS-X (and its precedent EXPRESS-V) (ISO 1996; Spooner and Hardwick 1997) is a schema translation language for both mapping among product models in EXPRESS (Schenk and Wilson 1994) and between a model and its views. As an extension to EXPRESS, EXPRESS-X allows the maps to be written entirely in this product modeling language. EXPRESS-X supports the development of complex maps, including one-to-one, one-to-many and many-to-many mappings. It only supports only one-way mappings, however; that is, it does not support mapping back to a source, updating existing instances. Another interesting mapping language is VML (Amor *et al* 1995). VML specifies maps as bi-directional relations between the source and target objects. Where applicable, this allows two-way mappings with one map. Compared to EXPRESS-X, VML allows finer-grained maps, and can better support incremental update. One weakness with VML is that it is not a full-fledged programming language; writing complex maps requires the use of linking in code written in a lower level language.

The research on specialized mapping languages, EXPRESS-X in particular, has addressed model transformation or updating. The fundamental idea in maps is the "coercing" of one type into another. Most computing languages provide some built-in coercions, for example from variables of type REAL to INTEGER. In C and C++, coercion is realized by cast operators. A mapping is between two models, a source and a target. A mapping language allows the definition of very complex coercions. A complex coercion is a hierarchical organization of lower level coercions. For example, from the bottom-up, a point coercion will convert coordinate values from one scale to another, then from one coordinate system to another, then to a new point format -- from a vector to individual coordinates, say. Maps thus are built up, from lower level maps to more aggregated level ones.

From the previous work in mapping languages and work at Georgia Tech, we identify the following issues regarding development of a general mapping language, capable of addressing any condition that may be encountered.

(i) Iteration of mapping operations in both directions require instance identification of source and target, so that the proper instance can be identified for updating. This allows just the update of the relevant entity and integration of the update with other data carried by the receiving entity instance(s).

(ii) Maps must deal with conditions where the map is not between one source and one target instance. Two different kinds of variations exist:

- One source instance may be mapped to multiple target types. This occurs when a single entity type represents multiple entity types in the receiving entity. An example might involve a schema having a single regular polygon structure, defined by a center-point, radius and number of sides, being mapped to a schema with rectangle, triangle and polygon entities. Each mapping creates one of multiple possible entity types. The reverse also may occur, where multiple source types may be mapped to a single target instance. These are examples of the one-to-many and many-to-one mappings.
- A source instance incorporating an aggregation structure maps to a receiving entity class with a different aggregation structure. In this case, the source entity part-of structure must be converted to a quite different part-of structure. The example above applies to this case also: a regular polygon inscribed in a circle has a different aggregation structure from one defined as a sequence of connected points. In this case, the mapping is

from a set of entities to another set of entities.

(iii) Mappings must deal with updates and also additions and deletions of instances. That is, one of the models connected by maps may delete or add entities, in addition to modifying them. Deletion and creation must be part of the map capabilities. These also must be managed with regard to instance identities.

(iv) Maps that involve a complex network of relations and not a tree, requiring multiple traversals of the entity structure. This may include merging several redundant entities into one or one into many. For example, multiple coincident polygon vertices in one representation may be defined as a single vertex in another representation.

No one mapping language has yet realized all these necessary conditions.

A related issue is that the map code, which does the updating from one model to another, defines dependency relations between the source and target. That is, the target data was defined through a dependency with the source data. If the source data changes, their target should receive a new update. A range of capabilities dealing with this and other types of dependencies has been developed in (Eastman 1996) and (Eastman, Parker and Jeng 1997).

3.5 Process modeling, planning and coordination

The last issue regarding data exchange architecture is based on the recognition that data exchange is embedded in the more general flow of work. The energy consultant needed specific information to undertake her assessment of lighting. Final layout of the service core in Scenario One could be realized only after other critical decisions, such as floor-to-floor height, were fixed. Tasks are dependent upon each other, requiring identification of which tasks and applications are needed to exchange with which others. Each of the scenarios presented reflect a workflow of design actions, coordinated between multiple people. Another general truth is that the process operating on some data and the product model carrying that data are interdependent. Modify the process—for example, change building fabrication from on-site to off-site factory fabrication—and the building model may need to change in response to different information needs.

A necessary component of complex data exchange scenarios, then, especially in a concurrent multi-user environment, is that there needs to be effective means to coordinate processes, introduce new ones, and to facilitate this coordination.

Currently, all examples of large-scale integration of computer applications in building start with a fairly fixed process model, allowing the information flows between applications to be planned for. CIMsteel has a general, fixed sequence of exchanges. The COMBINE project developed precedence models, called Project Windows, that depicted processes represented as Petri-nets. The current VEGA project is also is addressing process coordination.

Different processes carried out during the building life cycle will have different requirements for process representation. Some processes, such as building maintenance, will be scheduled and planned and the process model can be defined beforehand. Construction scheduling has a well developed set of practices and tools for process planning during the construction phase, but these change for each project. There have been some efforts to define a fixed process model for design phase activities. However, architects frequently make decisions during design that modify the future processes that are to be undertaken. Processes often change as design proceeds.

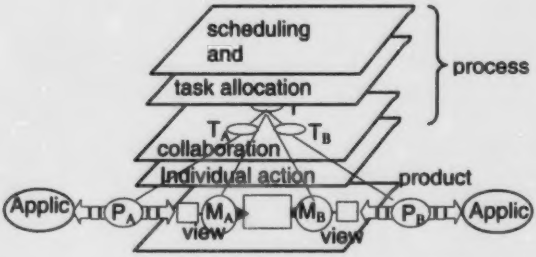

Fig. 6: A process layer is part of a building model, used to coordinate data exchanges

The recent Ph.D. thesis by Jeng (1998) proposes a multilevel structure for integrating process modeling for architectural design activities. The different levels have different associated functions.

1. The top level schedule is static, is based on inter-organization agreements and is often reflected in contracts. The process plan here is a linear sequence of processes, whose completion reflects various milestones. Payments and other organizational events are associated with the completion of processes defined at this level. The AIA standard contract, for example, outlines a five to seven phase process plan.
2. The second level is a task allocation level. All the top level activities are disaggregated to this level. The specific activities typically vary from project to project but have a general structure that is often defined well in advance (but may change occasionally). This level maps the overall process to groups or individuals, who assume responsibility for the activities. The sequencing of processes may reflect some general types of dependencies, but detailed interactions are assumed to be resolved at a lower level.
3. The third level of processes are the coordination and collaboration processes. The activities are dependency driven, being initiated in response to dependencies identified at the task level. They are adaptive, changing with the structure of the design. The activities involve communication and exchange of goals and low level schedules as well as design data. These processes are seldom scheduled in

current practice.

4. The bottom level are individual atomic activities carried out by individuals. They are the low level operations that are combined by an individual to accomplish the task laid out at the second level, augmented by the communication and collaboration tasks defined at the third level.

This four level structure distinguishes the fixed contractual coordination from scheduled task assignments that are assumed as responsibilities, separate from a dynamic coordination and communication level and a bottom level atomic level carried out by individuals. It offers a functionally defined framework for distinguishing process planning at different levels of aggregation, each level having its own functionality.

As an area of intellectual endeavor still in early development, the functionality supported by process modeling varies greatly. Some of the relevant functionality associated with process modeling are:

- *Static versus dynamic definition of processes*: A growing amount of software supports workflow management of information. These packages are based on repetitive and static workflows, requiring compilation and debugging. A few allow easy adaptation and change.
- *Explicit representation of resource allocation*: By their nature, process modelers represent processes. But when processes are allocated to machines or people, then there is a possible complementary representation of each resource that depicts its utilization over time.
- *Goal tracking:* As tasks are segmented and allocated, the goals associated with those tasks are also decomposed and allocated.
- *Change propagation:* Processes provide one means to track changes resulting from dependencies. A change in one activity implies the need to review all later processes that succeed the changed one.
- *Support for task execution:* Automating information used in processes can facilitate:

  - automated information distribution to enhance availability and productivity
  - review and approval processes
  - audit trail of process changes
  - resource allocation and management of bottlenecks

Different subsets of these features may be needed for representing the processes used in various building related tasks. Process modeling is receiving renewed attention as applications attempt to embed more functionality into process models. However, process models will need to be part of the work environment where data exchange is carried out at a distance.

4 Summary

It is fairly clear to anyone looking at the current building models and the tools now available to support them that there is a large gap still existing between what has been done and what is still needed. This paper has attempted to fill in parts of the gap.

The scenarios presented in Section 2 point out the importance of better specifying the detailed use and user requirements for data exchange, so that the exchange technology can be developed to support it. This calls for a human-computer interaction (HCI) perspective. While HCI is a growing area of study within the computer science field, there is a general lack of its application to the tasks within the architecture and building industry. Work is needed in this area to better understand the detailed structure and flow of information within different types of design, engineering and construction organizations.

While the EXPRESS language and associated tools have allowed significant progress to be made in the definition of data models for representing building information, this paper suggests that the information processing environment needed to support production activities within the building industry has not been as well developed. Among the areas needing development are:

- new, richer forms of exchange, including incremental updates, merging the output of multiple applications and distribution from one application to several
- exchange architectures that include multiple models which are not merged but are coordinated regarding their consistency
- better means to track data after it has been exchanged and allowing updates if it later changes
- coordination of data exchanges using a process model, so that critical predecessor and successor tasks are identifiable; the process model must be easily and possibly automatically modifiable

When considered closely against the requirements set forth in the scenarios, it becomes quite clear that EXPRESS was developed to explicitly support batch level file exchanges. It was also hoped that these facilities would be sufficient for more complex forms of exchange. However, clear requirements for more complex exchanges have not yet been developed. This is a clear need if we are to progress with effective data exchange in the building industry.

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207 IAI AND IFC-STATE-OF-THE-ART

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Abstract

This paper presents the current situation in IAI, the International Alliance for Interoperability, and the different versions of IFC, the Industry Foundation Classes. The issues presented in this paper include IFC versions from R1.0 to R3.0, the current IFC implementations and tools, IAI relations to ISO STEP, the current organisational structure of IAI and the possible future activities in IAI.
IAI is an open, worldwide organisation preparing an industry standard for architecture/engineering/construction/facilities management (AEC/FM) software based on product models. The modelling language is EXPRESS and data exchange format is the STEP physical file. .

Keywords: IAI, IFC, product data modelling, data standards, data sharing, AEC/FM, software implementation

1 IFC development chain R1.0 - R1.5 - R1.5.1 - R2.0 - R3.0

1.1 IFC release 1.0

The scope for IFC R1.0 was very limited; it included only five processes for architectural design, two for HVAC design, two for construction management and one for facilities management. Final Release 1.0 was published in January 1997.

The total schedule for IFC R1.0 was 16 months, from September 1995 to January 1997. IAI international "hard" cost was $60K and the estimated member contribution was $1.6M (See 1998).

The main results of IFC 1.0 were experiences for further IFC development as well as a pilot implementation for demonstration (demo software), which presented IFC functionalities. In total 17 companies made IFC R1.0 pilot implementations.

Durability of Building Materials and Components 8 (Volume Four). *Edited by M.A. Lacasse and D.J. Vanier.*
Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17743-9

1.2 IFC Release 1.5

The scope of IFC R1.5 incorporated feedback from the implementers, model architecture improvement, plug-in extensions and improved development tools. Final Release 1.5 was published in November 1997.

Twenty-seven software vendors participated in the IAI implementation program in R1.5 development. The total schedule was 10 months, from February 1997 to November 1997. IAI international "hard" cost was $225K and estimated member contribution was $250K. (See 1998)

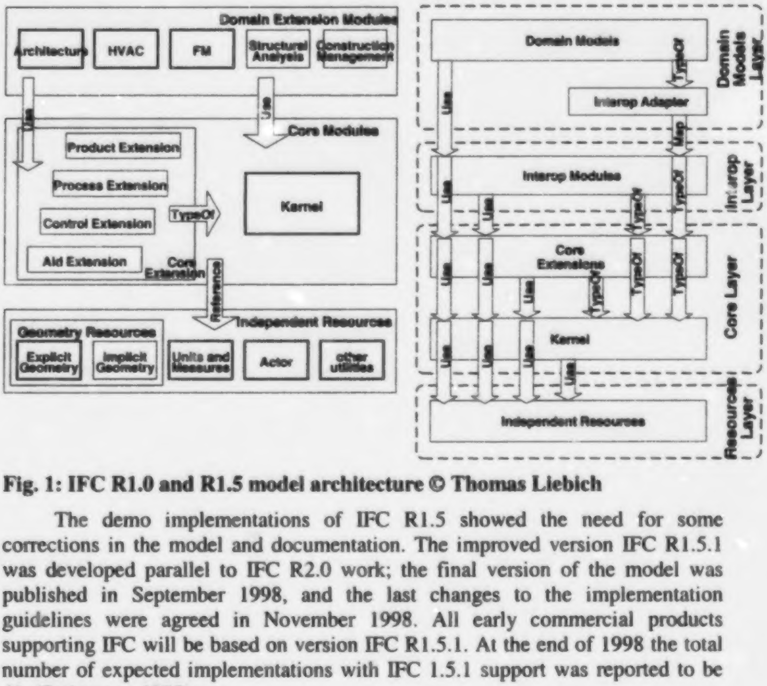

Fig. 1: IFC R1.0 and R1.5 model architecture © Thomas Liebich

The demo implementations of IFC R1.5 showed the need for some corrections in the model and documentation. The improved version IFC R1.5.1 was developed parallel to IFC R2.0 work; the final version of the model was published in September 1998, and the last changes to the implementation guidelines were agreed in November 1998. All early commercial products supporting IFC will be based on version IFC R1.5.1. At the end of 1998 the total number of expected implementations with IFC 1.5.1 support was reported to be 41. (Steinmann 1998).

1.3 IFC Release 2.0

IFC R2.0 is the first truly international IFC version, and its development has been the main activity in IAI since the beginning of 1998 until the end of March 1999. IFC R2.0 will be published in the IAI Summit in Washington April 1999.

The scope of R 2.0 includes architecture extensions, HVAC systems, code checking, cost estimating, occupancy management for facilities management (FM), property management, general-purpose networks and external document references. The schedule was 28 months, from December 1996 to March 1999. IAI international "hard" cost was $385K and the estimated member contribution was $2.5M. (See 1998)

1.4 R3.0 development

Parallel to the IFC R2.0 work, the IAI domain projects have been developing IFC R3.0. The scope has included more architectural elements, power and lighting systems, plumbing, structural systems, construction management, scheduling, temporary construction, more code checking, more facilities management, maintenance, area measuring, system management and referencing libraries on the web.

The current schedule is 30 months, from January 1998 to July 2000. The planned IAI international "hard" cost is $500K and the estimated member contribution is $5.0M (See 1998).] The plans are currently under discussion and will most probably change at the Washington Summit in April 1999.

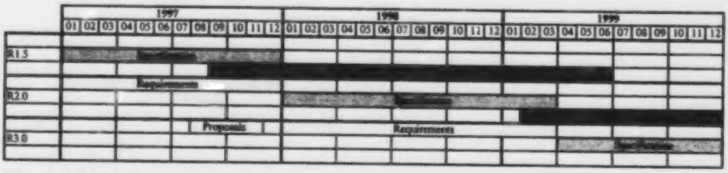

Fig. 2: IFC release schedule

2 IFC implementation and toolboxes

2.1 Implementation presentations of IFC R1.5

In 1998, several software vendors presented their implementations of IFC R1.5 in a series of A/E/C and CAD events around the world. The main events were:

- A/E/C Systems in Chicago, June 1998
- IAI Industry Day in Berlin, June 1998
- Australia Road Show in the InterBuild Trade Show, July 1998
- A/E/C Systems Show in Tokyo, September 1998
- SOLUBAT in Paris, October 1998
- ACS in Frankfurt, November 1998
- Nordic IAI Workshop in Helsinki, November 1998
- UK IAI Workshop in London, December 1998

The following summary of the demonstrations and the participating companies is provided to give an image of the possibilities in IFC 1.5 implementation.

A/E/C Systems in Chicago in June, 1998 demonstrated two processes. The first one was presenting architectural design and energy simulation possibilities in the early design phase by acadGraph, Nemetschek, Autodesk, Olof Granlund and PNNL. The second process presented architectural and HVAC design and cost estimation by Keops, Timberline, Muigg, RoCAD and Graphisoft

The A/E/C Systems Show in Tokyo in September, 1998 included two sequences of presentations from 11 Japanese companies. The first demonstrated architectural design, structural calculations, cost estimation and visualisation by

Graphisoft Japan, NEC Corporation, Japan Research Institute, KANEMATSU Electronics, Sumitomo Cement Computers Systems and Dynaware Corporation. The second presentation included architectural and HVAC design, fire alarm system and visualisation by Kozo Keikaku Engineering, FUJITSU, Informatix, Kyushu Institute of Technology, Chuden Computer.

At the **Frankfurt ACS** in November, 1998, the companies participating in the software demonstrations were acadGraph, Nemetschek, Graphisoft, Autodesk, Sofistik, Olof Granlund, RoCAD and Muigg. The show was also a turning point in IAI because several software vendors - Autodesk, Nemetschek, Graphisoft, Muigg and Olof Granlund - announced their IFC product releases. Alberti and NEC had announced their IFO products earlier. At that time, all available products were based on IFC R1.5 and were meant for test use by end users. The final products will be based on IFC R1.5.1, and the first ones were available in early 1999.

The Nordic IAI-Workshop in Helsinki in November, 1998 presented almost the same international demonstration as the ACS in Frankfurt, as well as, a Finnish project, which is a part of the national Vera programme. The project is called SPADEX (Spatial Data Exchange) and it is lead by Dr. Jarmo Laitinen from YIT. It demonstrated an information chain including architectural design (AIO Group: ARXi), precasted concrete elements (Cadex Software: ConcreteCAD), thermal simulation (Olof Granlund: SMOG), HVAC design (Progman: MagiCAD), production planning including cost estimation (YIT and Design Power Europe: COVE) and IFC model browser and VRML interface (VTT: ProMoTe).

2.2 Toolboxes, SDAI and other interoperability platforms

Several software vendors have already implemented tools to help IFC-compliant software development.

Most of the IFC 1.5 demonstration software has used the toolbox from **Concad (See Appendices 1 and 2)**, which includes library for read and write IFC files.

CSTB has developed a SDAI platform which can be used in two different ways: either as a generic STEP platform which can be loaded with any EXPRESS schema (late binding) or as a dedicated IFC toolbox where the platform is build with the IFC 1.5 schema and supports the associated algorithmic. This software implements the ISO 10303 SDAI (Standard Data Access Interface) and is delivered as an InProc (DLL) ActiveX Automation server; its interface is based on the C++ late binding of ISO 10303-23. It can be used within various programming environments including Visual Basic, Visual J++, and Visual C++, on both the Windows 95 and Windows NT 4.0 platform.

Muigg Computer Applications (See Appendices 1 and 2) has published a tool called Active-IFC, which has Active-X control to retrieve IFC-files. This tool enables easy Visual Basic interface programming to Active-X supported software, like MS Excel.

Nemetschek has developed a late binding data sharing platform (middleware) called o/p/e/n® - *Object-oriented Product model Engineering Network*. It is an open IT platform providing integrated support for the modeling and maintenance of complex products and entire business processes. It is an IT infrastructure for deploying product data in a distributed environment. The data model can be changed at run-time. The system can easily be adapted or extended to fulfill new requirements. O/p/e/n® provides the technology for integrating different applications that use the same data source. **(See Appendices 1 and 2)**.

VTT has developed a a generic schema and data browser called Promote. The schema browser generates Java classes and can create reproduced schema as a plain text and also as a HTML file, as well as browsing the content of EXPRESS schema in many views. Data browser enables viewing of STEP product data as an entity hierarchy and as a data content hierarchy-based tree, if it is supported in the schema. The software supports access to distributed models in client/server mode over the Internet. The browser can also create virtual reality models, which can be used as a 3D user interface to product models and related documents over the Internet. **(See Appendices 1 and 2)**.

2.3 Commercial Software with IFC R1.5.1 interface

One of the problem areas in IFC-compliant software development has been the compliance testing. IAI has been working on the issue for some time; but the final requirements and procedures are still unresolved. At the moment it seems that the first tools for compliance testing will be developed for IFC R2 and there will be no testing for the IFC R1.5.1 implementations.

The software vendors are usually not openly advertising their release dates in advance and, because the final implementable version of IFC R1.5.1 was published in late 1998, the final schedule for commercial software releases is difficult to forecast. The following list is therefore only a guess by the author. In 1998, Alberti by acadGraph, NcadArk by NEC and SMOG by Olof Granlund have already published commercial products based on IFC R1.5. Architectural Desktop by Autodesk and Allplan FT by Nemetschek also has IFC R1.5 interfaces available for end users, but they are meant for test use only. Graphisoft has promised that an IFC interface for ArchiCad will be available in summer 1999. At least these six commercial products, maybe more, will most probably be on the market at the A/E/C Systems Show in Los Angeles May 1999; but as indicated earlier, this expectation is based on a personal view of the author, and not facts.

3 Relation to ISO TC184/SC4 STEP

3.1 Liaison status and memorandum of understanding

IAI made a liaison agreement with ISO TC184/SC4 STEP in 1997. The proposal for a Memorandum of Understanding was formed at the IAI International Technical Management (ITM) meeting in Nice January, 1998 and was approved by the STEP Building Construction group in Orlando in February, 1998. IAI International Council approved the documents officially in Copenhagen in April, 1998; whereas ISO TC184/SC4 did the same in the Bad Aibling in June, 1998.

The objectives of the MoU are to strengthen development efforts for building construction within ISO TC184/SC4 through technical input and participation by IAI member companies and to strengthen development of the IFC within the IAI through technical input and use of appropriate within the purview of ISO TC184/SC4.

3.2 Joint meeting in Munich August 1998

At the joint IAI ITM/STEP Building Construction meeting in Munich August, 1998, the following agreements were approved:

- Develop links between IFC and STEP Part 225
- Develop links between IFC and STEP Part 230
- Joint trial interpretation of elements of IFC Core (as STEP Part 106)
- Hold more joint meetings
- Collaborate on the CDS and DXF2 drawing exchange developments
- Review EXPRESS 2 specification
- Investigate the most appropriate approach to standardisation of IFC
- IAI participation in meetings on Technical Architecture in Bad Hennef
- All IAI documents are publicly available except the formal model
- IAI wants to encourage STEP members to review the IFC model. The IAI International Technical Director (See Appendix 1) can be contacted to obtain access to the model

4 Organisational structure of IAI

In 1996 the IAI changed its name from the Industry Alliance for Interoperability to the International Alliance for Interoperability. Currently, IAI has nine regional Chapters with more than 600 member companies from 20 countries. The Chapters are Australasia, French speaking, German speaking, Japan, Korea, Nordic, North America, Singapore and the United Kingdom.

Until the Copenhagen Summit in April, 1998, IAI was on the international level only as a voluntary co-operation of these regional Chapters. In Copenhagen, IAI started a process, which is aiming to form an international legal entity at the April 1999 IAI Washington Summit. In Copenhagen, the organisational Charter was formed in the model shown in **Fig. 3**. In Copenhagen, the Executive Committee included three members and one deputy, at the Paris Summit in October, 1998; it was expanded to the current five members and two deputies.

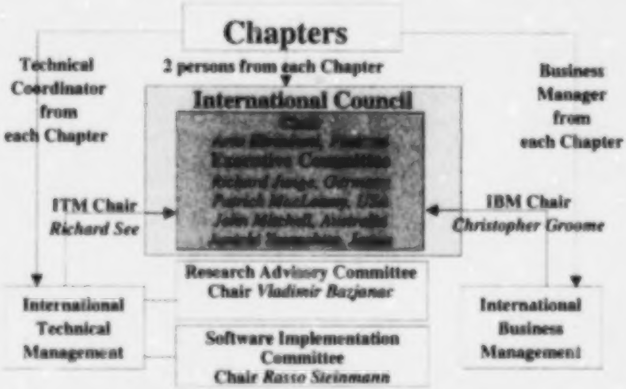

Fig. 3: IAI organisational structure

At the Paris Summit in October, 1998, the structure of technical committees was changed so that all project leaders were included as members in the International Technical Management group, as shown in **Fig. 4**.

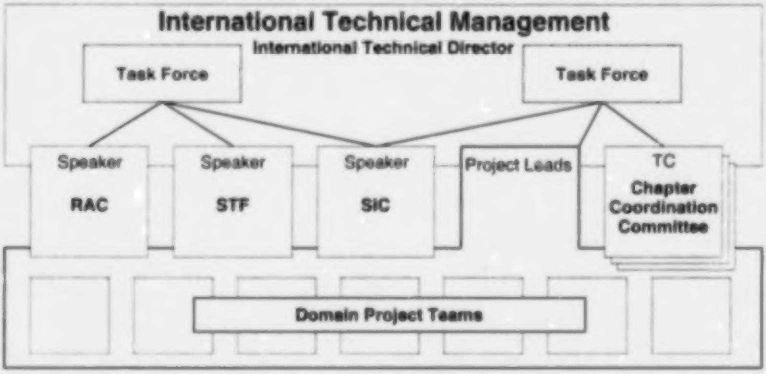
International Technical Management
International Technical Director
Task Force
Task Force
Speaker
RAC
Speaker
STF
Speaker
SIC
Project Leads
TC
Chapter Coordination Committee
Domain Project Teams

Fig. 4: ITM and other technical committee's © Richard See

5 Future plans after Washington Summit April 1999

The year 1998 has been a period of strong changes in IAI. At the moment (March 1999), the situation is very open and therefore the view presented here is the personal view of the author, and not an official statement by IAI. At the time of presentation of this paper in Vancouver in May, 1999,we all will know which of these alternatives will come true or if the April, 1999 Washington Summit found some new solutions.

The funding problems for the IAI have been increasing because of several reasons. The budget of IAI has always been very limited in relation to the scope of the venture. The number of members in all Chapters has not increased as the Chapters have hoped. On the contrary, the expectations of new members were maybe set too high in the beginning and now the effect can be seen in some Chapters as frustration, because the software products are not yet on the market. The decision made at the Copenhagen Summit in April, 1998 fixed the delivery of IFC R2.0 to April 1999 and although the Specification Task Force has been able to work on schedule and under budget, a major part of the funding for 1999 will be already used before April 1999. This means that the funding for the rest of 1999 is much too low compared to the scope of IFC R3.0; and IAI must find new ways to fund the future work.

The Paris Summit in October, 1998 introduced a project-based funding model where the international costs based on membership fees would be cut to the obligatory administration and model integration work, or project funding would even cover that part. The main problem in this funding model is that the domain projects for IFC R3.0 have already worked based on the old funding principles. It seems very difficult to find project funding for the existing projects, and it is also impossible to ignore the work, which the domain projects have already done for over a year. In principle, all Chapters agree that in the long run the project funding must be adopted, but the transition period will be a problem.

The project based funding will enable an approach where companies or other organisations can fund the projects, which produce the functionalities they need in their own activities. This kind of funding is always much easier to find than overall funding for general purposes. The danger of course is that there will be no general view of development needs in the model and all projects will concentrate on short-term goals and immediate needs in the funding companies.

At the January, 1999 San Francisco Executive Committee (ExCom) meeting, a so-called "Quick R3.0" plan was introduced. It basically meant that immediately after IFC R2.0 announcement, IAI would start the IFC R3.0 development with a new scope. The schedule aimed to a frozen model by October, 1999, with full documentation by the end of 1999. The goal of this plan is that the first IFC R3.0 products could be published by the time of A/E/C Systems Show 2000. The scope would include core stabilisation, up- and downward compatibility and very few new functionalities. Most R3.0 projects would be sifted to IFC R4.0, where the schedule is still open. The main problems in this model are the implementation support for IFC R2.0 and the possible frustration in the R3.0 domain projects.

To avoid these problems, the author proposed that after the January, 1999 San Francisco meeting that IAI should work with IFC R2.01 after April 1999 and continue with IFC R3.0 for the agreed schedule (July 2000) or, if necessary, lengthen the schedule until October 2000. The scope for IFC R2.01 would include model improvements based on the early implementation of R2.0, up- and downward compatibility and core stabilisation. Some new functionalities with minor impact to the model could be added only if the projects have full funding including the integration work. In this development model, IFC R2.01 products could be on the market by the time of A/E/C Systems Show 2000 and IFC R3.0 products at A/E/C Systems Show 2001.

In any case, all members in the IAI technical teams agree on the need for early commitment and comments from software vendors for model development. Currently the problem has been that the final review and comments come too late.

Usually that happens when the model is already finalised, which means an improved or corrected version of each release.

Other open issues are the organisation, especially for the technical team, procedures for the new project proposals, funding for international work, release schedules and the final form of the constitution. The Washington IAI Summit in April, 1999 will be crucial for the future activities in IAI.

6 Concluding remarks

Despite of the current problems, IAI has been a success in many ways:

- Three major releases and one minor one in 3.5 years
- IFC Release 2.0 will be published on schedule and under budget
- Integrated AEC information model - nearly 300 object classes and over 400 object types
- 16 IFC R3.0 domain project requirements nearly complete with much better requirement specification than in previous releases
- 33 vendors have demonstrated software and evidence that more applications are coming, four software vendors shipping, five more have extension modules available, and three more will ship later this year
- Increasing visibility on many levels: research conferences and papers, press and the most important issue: AEC/FM industry customer awareness

7 References

See, Richard (1998) IAI International Technical Director, Personal Communication.

Steinmann, Rasso (1998-99) IAI Software Implementation Committee Chair, Personal Communication.

Appendix 1: IAI International contacts and IAI related web links

International contact persons:

Council and ExCom Chairman	Arto Kiviniemi	arto.kiviniemi@vtt.fi
Technical Director	Richard See	richard.see@ibm.net
Assistant Technical Director	Jiri Hietanen	jiri.hietanen@qpartner.com
Business Manager	Christopher Groome	brt-groome@dial.pipex.com
Research/Advisory Committee	Vladimir Bazjanac	V_Bazjanac@lbl.gov
Software Implement.Committee	Rasso Steinmann	rasso.steinmann@ibm.net

Web links to IAI Chapters:

International IAI site	http://www.interoperability.com/
or	http://iaiweb.lbl.gov/
IAI Australasia Chapter	http://www.interoperability.org.au/
IAI French Chapter	http://mediaconstruct.cstb.fr/actb.html
IAI German Speaking Chapter	http://mtr.opb.de/iai/
IAI Japan Chapter	http://www.interoperability.gr.jp/
IAI Korea Chapter	http://italab.kyunghee.ac.kr/iai_korea/
IAI Nordic Chapter	http://www.vtt.fi/cic/niai/
IAI North American Chapter	http://iaiweb.lbl.gov/Chapters/North_America
IAI Singapore Chapter	http://www.ncb.gov.sg/ncb/construction/iai/
IAI UK Chapter	http://helios.bre.co.uk/iai/

Web links or contacts to software or toolbox vendors:

Autodesk - IFC	http://www.autodesk.com/products/ifc/index.htm
Bentley - IFC	http://www.bentley.com/news/99q1/iai.htm
Concad - toolbox	Bernd Ingenbleek <bernd@concad.de>
CSTB	http://www.cstb.fr/
Graphisoft - IFC	http://www.graphisoft.com/corporate/press/dxf.html
Muigg	http://www.muigg.com/
Nemetschek	http://www.nemetschek.com/
Olof Granlund	http://www.granlund.fi/
RoCAD	http://www.mum.de/produkt/haustec/rocadhaus.htm
Sofistik	http://www.sofistik.de/
Timberline	http://www.timberline.com/
Visio	http://www.visio.com/
VTT - Promote	Tero Hemiö <tero.hemio@vtt.fi>

Appendix 2: Software commitments *[Steinmann 1999]*

It is expected that 41 software vendors will implement IFC Release 1.5.1:

French Speaking Chapter (5):

Batisoft	CAD for architects, announced IFC support
BBS SLAMA	HVAC
CSTB	SDAI toolbox, middleware, IFC 1.5, 1.5.1&2.0 support
KEOPS	CAD
XD2 Allsystem	Cost estimation

German Speaking Chapter (8):

acadGraph	Conceptual design, CAD for architects, IFC 1.5 support
Concad	Toolbox, IFC 1.5 & 1.5.1 support
Graphisoft	CAD for architects, announced IFC support in 1999
MB	CAD for architects
Muigg	CAD for architects, Active X-control, IFC 1.5 support
Nemetschek	CAD for architects, CAD and FEM for structural engineers, structural analysis, FM, IFC 1.5 support, Middleware, IFC 1.5, 1.5.1&2.0 support
RoCAD	HVAC design, IFC support in 1999
SOFiSTiK	CAD and FEM for structural engineers, IFC support in 1999

Japan Chapter (11):

Chuden Computer	HVAC
Fujitsu	CAD for architects
Hitachi	Elevator Setting Design
Informatix	CAD for architects
Japan Res. Inst.	Structural Design
KANEMATSU	CAD for architects
Kozo Keikaku	CAD for architects
Kyushu	Equipment
NEC	CAD for architects, IFC 1.5 support
Sumitomo	Equipment
Yondenko	HVAC

Nordic Chapter (9):

AIO Group Oy	CAD for architects and electrical engineers
Cadex Oy	CAD for concrete design
Jidea Oy	CAD for architects and FM software
Olof Granlund Oy	CAD and building services, IFC 1.5&1.5.1 support
Progman Oy	CAD for HVAC engineering
Tietovalli Oy	Software for HVAC contractors
ToCoMan Oy	Software for the main contractors
Viatek Oy	FM software
VTT	PM browser, JAVA and VRML, IFC 1.5&1.5.1 support

North American Chapter (8):

Autodesk	CAD for architects, CAD platform, IFC 1.5 support
Bentley	CAD for architects, CAD platform, announced IFC 2.0
CIFE	Construction management, scheduling
Marinesoft	Thermal calculation
NAOKI	FM software
PNNL	Energy code compliance checking, IFC 1.5 support
Timberline	Cost estimation
Visio	Drawing and 2D CAD

PART FIFTEEN

COMPUTER-INTEGRATED CONSTRUCTION

208 A PROTOTYPE DISTRIBUTED CIC SYSTEM BASED ON IAI STANDARDS

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Abstract

A prototype Computer Integrated Construction system is being developed that models building product and process information using International Alliance for Interoperability standards. The goal of this research is to provide a window into the future of how these standards can be applied in the construction industry. The prototype consists of a project database that is structured according to a common project schema or project data model. The schema is based on emerging International Alliance for Interoperability standard models but it is implemented in a way that allows the dynamic development of the schema (and even of its underlying metamodel) without destroying the information in the database in order to support on-going work in the development of information model standards. The system is modular in nature so that it can be supplemented with plug-in tools to accomplish a variety of project management tasks. It is served over the web through a combination of Microsoft's Active-X Data Object technology and a lightweight version of ISO STEP's Standard Data Access Interface. Data sets served to the client are wrapped in the Extensible Markup Language to allow for the self-description of information.

Keywords: Computer Integrated Construction, IAI, IFC, Product Models, Process Models

1 Introduction

The essence of planning is to combine all aspects into one feasible process, which means that information has to be transmitted, transformed and combined. The increased complexity of buildings and of the organization of the construction process has made the transmission and sharing of information more difficult as there is a growing amount of information to be consolidated, distributed, and exchanged

Durability of Building Materials and Components 8 (Volume Four). *Edited by M.A. Lacasse and D.J. Vanier.*
Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17743-9

(Jägbeck 1998). Unfortunately, most of the software tools used to generate this information cannot interoperate. In practice, paper drawings or documents are therefore the common medium for exchanging information. Consequently, the manual input of data from one tool to another and the associated risk of error dramatically hamper the duration, quality and cost of the construction process (Debras et. al. 1998). The result is a need for more explicit and self-contained (i.e. less context dependent) information (Jägbeck 1998). The construction management group at the University of British Columbia is addressing this issue through the development of new computer-based tools to support construction management and to increase the overall efficiency of construction operations.

We subscribe to the vision that the architecture, engineering, and construction (AEC) industry will evolve to one in which detailed, integrated, computer-based models of the AEC projects act as the predominate medium for carrying out design and management work and for communicating the results among project participants (Froese et. al. 1997). To this end, the Construction Management Group has developed the TOPS (Total Project Systems) model. TOPS is a conceptual model that provides the basis for the development of Computer Integrated Construction (CIC) systems. The TOPS model is founded on three principal research thrusts: application development, shared project representations, and system architectures and interfaces (Russell and Froese 1997). Much work has been done on application development (see Rankin et. al. 1998; Froese et. al. 1997; and Rankin et. al. 1997 for examples) and shared project representations (see Froese and Rankin 1998; Russell and Froese 1997; Yu et. al.1997; Froese 1996; and Fischer and Froese 1996 for examples). Current research is focussing on the design, development, and prototyping of a system architecture and interface(s) for use in TOPS.

TIP (TOPS Implementation Prototype), the prototype CIC system under development, models building product and process information using IAI (International Alliance for Interoperability) standards. The on-going goal of this research is to provide a window into the future of how IAI standards can be applied in the construction industry. The prototype consists of a project database that is structured according to a common project schema or project data model. The schema is based on emerging IAI standard models, but it is implemented in a way that allows the dynamic development of the schema (and even of its underlying metamodel) without destroying information in the database in order to support on-going work in developing project information model standards. The system is modular in nature so that it can be supplemented with plug-in tools to accomplish a variety of project management tasks. Current plans include the development of a short cycle scheduling tool. TIP is a distributed system, served over the World Wide Web through Microsoft's Active-X Data Object (ADO) technology wrapped in a data access layer that we are developing called the, Lightweight Data Access Interface (LDAI), which can be thought of as a simplified and flexible development version of the ISO STEP Standard Data Access Interface, SDAI. Data sets served to the client are encoded in XML (Extensible Markup Language) to allow for self-description of information.

2 TIP Architecture

Figure 1 illustrates the architecture of the TIP system. Froese et. al. (1997) characterize the underlying architecture of this class of system as: *open*, in that it is not dependent on specific computing technologies (e.g., it is based on international data standards, it is platform independent, etc.); *modular*, such that a variety of specific applications developed by different sources can be brought to bear as appropriate to create the overall system; and *distributed*, by recognizing the requirements of a variety of users and data sources.

Application modules are connected to the system using standard interfaces. Thus, they can be updated without the need for changes to other parts of the system. Not only is project data shared, the application modules are also shared by different participants at different locations. As the applications and project data are transparent, users must simply send requests to the system through the user interface, invoke appropriate modules, and input the appropriate data. (Froese et. al. 1997)

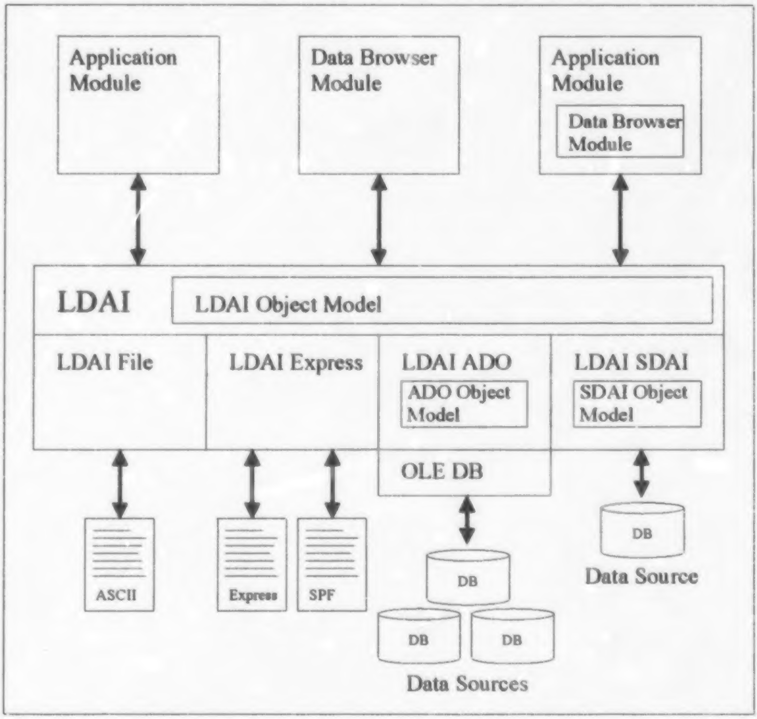

Fig. 1: TIP architecture

3 LDAI

Applications interact with the integrated system through data access interfaces that are structured according to underlying schemas or data models (in this case, the LDAI object model), which are in turn structured on underlying assumptions about the structure of primitive concepts such as objects, classes, etc. (i.e., the metamodel). The LDAI (lightweight data access interface) defines a functional interface between an application and one or more collections of data. The LDAI is a data access, or "middleware", component. It is similar to other data access interface standards such as the ISO STEP Standard Data Access Interface, SDAI (see International Organization for Standardization (ISO) 1995 for an explanation of the SDAI). We are developing the LDAI, rather than directly adopting the SDAI or another system, because our requirements for a middleware layer are quite different, stemming largely from the fact that we wish to support rapid prototype development in an area where "standards" are frequently changing, rather than support production software. The LDAI, then, has the following defining characteristics:

- It is very simple to work with. It is implemented in Visual Basic and it provides only the most essential and generic data access functionality (it can be thought of as a stripped-down version of the SDAI).
- It can be used as a "front end" interface for a wide variety of data access "back ends", such as EXPRESS, STEP Part 21, or XML files, or SDAI or Microsoft ADO data access interfaces (and it can act as a translator between these different formats).
- Only the smallest possible set of core metamodel data structures are statically encoded in the LDAI; other aspects of the metamodel and all project data models are dynamically loaded at run-time (i.e. late binding) and these models can be altered at any time.
- The LDAI object model is presented in UML notation in Figure 2. We are using UML (see UML Resource Center 1999) notation for developing the LDAI since it is becoming a standard within the software industry for representing data models and other portions of software designs and because we have found more support for UML within development tools than for EXPRESS. We expect to provide the LDAI with the capability of importing and exporting EXPRESS and possibly UML information as well.

The TIP metamodel is drawn directly from this LDAI object model. An important function of this model is its ability to evolve its schema. The main reason for this in our case is that we are developing prototype integrated applications based on standard project data models concurrent with the ongoing development of the standard data models themselves, so the applications' underlying data structures are frequently changing. This capability can also be important for end users to allow the underlying conceptual model used by the project actors to be altered and to evolve over time (by adding, deleting, or modifying an object type property), without affecting the overall consistency of the project information base. (Rezgui, et. al. 1998) The LDAI object model implements schematic evolution by early binding only the smallest possible metamodel structure. All other metamodel constructs are

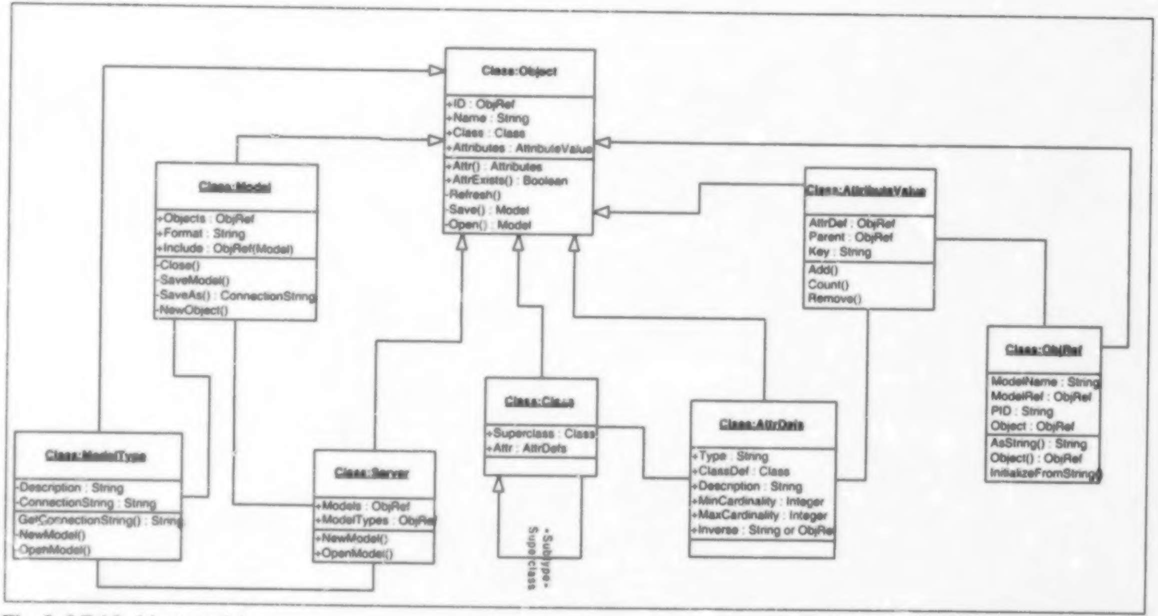

Fig. 2: LDAI object model

built up dynamically as necessary at runtime, and changes can be made to the schema even after it has instance data associated with it. Although the LDAI will be able to maintain data consistency for most types of simple changes to existing schemas, it leaves the ultimate responsibility for maintaining data integrity during schematic evolution to the application developer and users.

It is important to note that LDAI is not intended to provide a new standard for functional interfaces between data and applications, nor is it a replacement for the SDAI. The LDAI is a development interface rather than a production interface. It is advanced as a simple and flexible tool to facilitate the quick development of prototype systems. In a full implementation of TIP, the LDAI would be replaced with an SDAI or other data access interface.

4 ADO

The following is excerpted from Microsoft's white paper on Universal Data Access (UDA) (Microsoft 1998). ADO is a part of Microsoft's UDA initiative. The premise of UDA is to allow applications to efficiently access data where it resides without replication, transformation, or conversion. Open interfaces allow connectivity among all data sources. Independent services provide for distributed queries, caching, update, data marshalling, distributed transactions, and context indexing among sources.

ADO is a set of high-level automation interfaces over OLE DB (OLE DB is the Microsoft system-level programming interface to diverse data sources). It enables applications to access and manipulate data in a database server through an OLE DB provider. ADO is provider neutral. That is, although it allows access to the full range of OLE DB data, it does not implement its features specific to any one provider or data source. Underlying ADO are four service components that implement its functionality. These services are outlined in Table 1.

Table 1: ADO services

Service	Description
Cursor	Data fetching, data manipulation, local updates, local cursors
Synchronization	Propagates updates to the data source, refreshes the cursor from the data source, and coordinates conflicting updates
Shape	Provides a hierarchical view of data to offer a flexible view of the data set
Remote Data Service	Permits interaction with OLE DB data sources over the Internet

ADO will be wrapped in LDAI. The result is that the functionality of ADO, and the ADO service components, will be transparent to the user.

5 Implementation

The software architecture of TIP was presented in Figure 2. The data repository system will be implemented as a relational database in Microsoft's Access 97. Schemas stored in the database will be IAI models with possible extensions for application-specific functionality. An OLE DB server will be used to serve the database, making it accessible to the Internet. The TIP system will implement the LDAI with four backends: LDAI text files; LDAI Express; LDAI ADO; and, LDAI SDAI. The LDAI File and LDAI Express backends read and write local files. LDAI text file reads and writes LDAI notation in ASCII format. The LDAI Express backend imports or exports Express and SPF (STEP Physical File format) type files. The LDAI ADO backend is the interface that allows the LDAI to use ADO to communicate with data sources. Finally, the LDAI SDAI backend is an interface allowing information to migrate between the LDAI and the SDAI. Of these four backends, current plans are to only implement the first three. The LDAI SDAI backend will be implemented later.

At the application level, three classifications of modules are shown. The data browser is a general purpose user interface to project data that is an integral component of TIP. This data browser can serve as a separate tool or application, similar to that of the Explorer tool in Windows. Its purpose is to allow users to enter, view, and manipulate project data as well as view and modify the underlying models and schemas. The data browser interface can also be incorporated into other, more specialized applications (as shown by the combined Application Module/Data Browser Module element). Finally, the generic application represents any standalone module that plugs into the LDAI to access project information. A variety of applications can be developed—estimating, scheduling, quality control, or document management systems for example—so long as the required underlying schemas have been installed to support the application module.

At present, a short cycle scheduling application is being prototyped. The application is designed for use by construction managers to create on-site look-ahead schedules and to schedule work-in-place activities and materials delivery. A scheduling application was selected for development purposes as scheduling draws upon a broad range of project information (i.e., product, process, and resource information). For example, activities, sequencing, cost, the assignments of resources to processes, etc. As a result, we expect this application to provide a good test of emerging IAI models of construction process-related information. Future papers will report on the implementation of the scheduling application and the performance of the IAI models.

The language binding for TIP is Visual Basic. The data browser and application modules are being developed in a standard web browser environment (Microsoft's Internet Explorer) in order to take advantage of the functionality of ADO. A separate data repository is being created to store XML code. ADO will be used to wrap project data in XML to create a data set that is self-describing.

6 Conclusion

This paper has described the continuing development of TOPS by the Construction Management Group at the University of British Columbia. Current research focuses on migrating the TOPS conceptual models to a prototype implementation, TIP. The TIP model addresses the three research thrusts of TOPS: application development, shared project representations, and system architectures and interfaces. The LDAI was introduced as a prototyping mechanism that allows the dynamic modification of the underlying schemas and metamodels without affecting instantiated project data. Prototyping of the system, and a short cycle scheduling application module, is underway and testing is expected to begin in the near future. Results from the complete prototype implementation and field trials will be reported in future papers.

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209 INTEGRATION OF PLANNING AND CONTROL ACTIVITIES FOR BUILDING AND CONSTRUCTION: EXPERIENCING STANDARDS

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Abstract

The effective exchange of information regarding the planning and control activities (schedules, resources, materials, cost, cash flow) between the different parties involved in building and construction projects is a critical success factor to avoid projects' time and costs overrun and to insure better quality. However, current applications and research and development efforts on electronic exchange of information are usually restricted to the exchange of technical design information, particularly CAD exchange amongst designers and between these and contractors; and of business data (purchase orders, invoices, remittance advice, etc.), between contractors and builders, merchants and suppliers. This paper will review current practitioners' approach to the exchange of planning and control information, and discuss the business need to the seamless flow of scheduling, resource, materials, and cost information between firms. Different technical solutions available to address the subject will be described. Through the description of the experience in this area of two European projects, RoadRobot and SUMMIT, the paper will also describe the state-of-the-art regarding the development of international standards for the exchange of planning and control information, particularly at the EDIFACT, STEP and IAI levels. RoadRobot – Operator Assisted Mobile Road Robot for Heavy Duty Civil Engineering Applications, was a project devoted to implement a general standard-based architecture to support the information management for road construction environments, covering from the road design to road construction, embracing the site, cell, machine and tool levels. SUMMIT – Supply Chain Management In Construction Industry, is an end-user driven project which envisages the creation, implementation, test and evaluation of an EDI, STEP and IAI/IFC based communication infrastructure on a specific project of building prefabricated houses, connecting project manager, contractor and suppliers. This paper shows that international standards for planning and control information in B&C are not yet enough developed and that further developments are required.

Keywords: Integration, interoperability, modelling, planning & control, standards

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1 Introduction

The integration of Information Technology (IT) into the Building and Construction (B&C) industry has not achieved yet a satisfactory degree of research and development work. No special amendments have been paid to this industrial sector, including the major areas of the building industry, suchlike the outdoor construction of dams, roads, airfields and other large projects.

Regarding the state-of-the-art in integration of new technologies into building industry, including IT, the results are still very poor. Most established developments are concentrated on the Computer-Aided Design (CAD), drafting, scheduling control of tasks, and automation of certain pre-fabrication processes.

Nowadays, no special attention has been given to the automatic data flow of planning and control information, or advocating about the business needs to the seamless flow of scheduling, resource, materials, and cost information between firms. For practitioners in these industrial environments, very often time and material planning are done in a manual process at the construction site in a standalone basis, most of the times assisted by data received on phone calls or paper support (Pimentão et al. 1994).

Up to now, only little research work has been undertaken into the development of overall control architectures for building sites, whereas the development of such control architectures for other industrial sectors has advanced significantly during the last years. The question is now, whether the results of the past developments can be transferred to the demands of the building and construction industry. The evaluation and improvement of architectures and modules coming from other industrial areas (Camarinha-Matos and Osório 1992) seem to be necessary.

For that reason, to learn from existing architectures and modules from other industrial areas, according the special requirements of the building industry, can help to find new ways towards fully or partly automated and integrated construction processes (Sousa.1998; Jardim-Gonçalves et al 1997).

Future developments have to focus at the integration of IT into the building industry (Bradley 1991). Besides the low-level automation of overall planning and control systems, the task-level programming of complete building sites has to be achieved. The main interest of future works lies in the development and elaboration of a generic architecture for standardised integrated indoor and outdoor construction sites. Therefore, further work should also be concentrated on the automation of specific heavy-duty machines (Ulrich 1991; Leidinger 1991) in order to obtain a manpower reduced building site, with computer integrated time scheduling and material planning possibilities. Also the integration with the commercial aspects related with the Building and Construction business should be considered, towards a complete and automated data flow among the internal (construction) and external (business) actors performing in this industrial sector.

The adoption of standards in modeling, using a specific data protocol to support the integration and flow of information using a unique data exchange format, to be adopted by the various activities in B&C environments is, for sure, a key factor where proposals are now starting coming out. Examples are the work being developed by STEP within ISO TC184/SC4 Building and Construction Working Group (STEP 1999), by International Alliance for Interoperability throughout its Industrial Foundation Classes (IAI/IFC 1999), and UN/EDIFACT

(UN/EDIFACT 1999) and its related adaptations.

2 Experiencing ISO 10303 - STEP in road construction

The purpose of the European ESPRIT 6660 RoadRobot (Operator assisted Mobile Road Robot for Heavy Duty Civil Engineering Applications) (Pimentão et al 1994) project was the definition of a flexible control architecture suitable for outdoor heavy-duty construction applications, towards an automated construction site involving mobile equipment, concerning the building industry requirements.

Recognising the low level of IT in building industry, the focus point of interest was to develop information technology for the specific requirements of this sector. Therefore, the knowledge and experience brought in by the building industry, the manufacturers of heavy-duty building machines, companies with special IT expertise, and the R&D institutes, was very important.

After system's analysis phase with road construction companies, it was realised that applications used by most companies were spreadsheet-based, and these were applied just for some of the planning and scheduling tasks. Therefore the development of some specific applications was required in order to complete the construction process cycle.

Since the purpose was to produce a flexible architecture, the consortium agreed on the use of standards. This would provide the flexibility of the solution and they provided a reliable way to produce an open architecture where new software tools could be added without restrictions on vendor's specific data formats.

The development status of STEP (ISO Part1 1992) by that time (1992) and the previous experience of UNINOVA on its application for the furniture industry (Jardim-Gonçalves et al 1993, Jardim-Gonçalves et al; 1994), led to the adoption of this standard for the data modelling within RoadRobot (Jardim-Gonçalves et al 1996). The data was modelled using the EXPRESS language (ISO Part11 1991), while for data representation the Part21 of STEP (ISO Part21 1992) was adopted.

2.1 Architecture of RoadRobot

The first problem to be addressed was "how to model a road throughout its life cycle?" (Jardim-Gonçalves et al 1995). Aware of the "Road Model Kernel" (RMK) developed by TNO and the Dutch ministry of Public Works, the consortium adapted and improved it, since the status of RMK model in those days lacked features that were needed for road construction, such topological and geological data for excavating.

Other models were also developed to represent the road construction process at the various levels of the architecture, such resource models, task models, planning information and scheduling information (Pimentao et al 1994).

The architecture of RoadRobot devised for the project has four logical levels: (1) Site, (2) Cell, (3) Machine and (4) Tool (Pimentão et al 1993), as depicted in Figure 1 where level 3 and 4 are represented together. In this case, production of information starts loading into the RoadRobot Information System (IS) the information produced by a CAE system (in this case the InRoads package from Intergraph), using a tool that we called "Project Development". After that, the information is decomposed and processed in order to produce the tasks. Task decomposition is performed in a semi-automatic way with the aid of a Decision Support System (DSS). Regarding the road construction section, the DSS looks at the geometrical and geological information and, based on a set of rules supplied by the experts (e.g. two-lane road produce a task per lane), and on equipment restrictions such as excavator arm length, to produce the tasks.

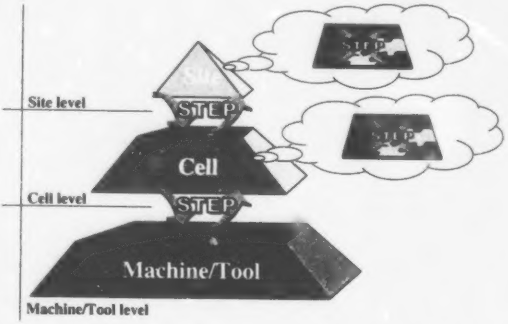

Fig. 1: RoadRobot's architecture. Integration within and with logical levels

Each task is then assigned to a given construction cell-type. Cell types are based on the characteristics of the set of equipment that composes it (e.g. paving cell). Task sequencing is performed with the help of a planner and task scheduling follows it with the assignment of existing equipment to each cell and effective time scheduling. At due time, the Site Operator is supplied with the information needed for setting up the given Cell, and once the Cell reports its operational status, it is fed with the task information. Machines, tools, operators and workers are also fed in an identical way.

Within RoadRobot's architecture, STEP is not only used for the modelling of the data to be transferred among applications within a given controller (e.g., Site/Cell), but also for the modelling of the information passed among controllers, like tasks, commands and responses. Therefore, all information flows within RoadRobot were modelled using STEP, including data and control flows, the last based on a specific model for controlling messages.

3 SUMMIT project

The ESPRIT 25559 Project Supply Chain Management in Construction Industry – SUMMIT, is to create, implement, test and evaluate an EDI-based communication infrastructure between the various partners involved in the manufacturing and construction of prefabricated houses (SUMMIT 1998). This infrastructure is to automate the tendering, ordering, delivery, invoicing and payment processes of house systems, equipment and services in its supply chain, whose members have different levels regarding Information and Communication Technologies (ICT).

SUMMIT is dedicated to the exploitation of potentials of both EDIFACT and STEP approaches to product and process data communication, by a concept of combining the complementary nature (business versus technical data) of both approaches. This, together with an EDI system based on an inter-organizational workflow system, will enable a better co-ordination between the companies on the supply chain, from the client's representative (project manager), to the contractor, and suppliers. Major results envisaged by SUMMIT are:

- A procurement process model exploiting the potential of pure digital data exchange and system interoperability
- EDIFACT messages sub-sets for the procurement of house systems and equipment
- STEP/IFC product model enabling the representation of project management data for houses
- An EDI communication infrastructure featuring secure and compatible information exchange for the entire production process
- A distributed information flow component based on EDI and inter-organizational workflow infrastructure supporting process definition and process execution the boundaries of autonomous organizations
- Two prototype implementations of business chains scenarios in a real world environment with realistic test data among a project manager (client's representative), a prefab house manufacturer, and its suppliers and subcontractors.

SUMMIT project started in December 1997 and results should be ready by October 1999. In the meantime, developments so far are partly described below.

3.1 SUMMIT developments in EDIFACT

Many groups of firms, within different industries, industrial sectors, associations, and different countries have defined proprietary formats for the exchange of administrative data. However, some years ago the United Nations started an initiative to define system neutral messages for administrative business processes. Nowadays, there are about 200 UN/EDIFACT (United Nations Electronic Data Interchange for Administration, Commerce and Transport) internationally agreed messages available at various stages of development. The trend is for old proprietary, idiosyncratic EDI systems to migrate towards EDIFACT, and new developments to be based on this standard (Jayachandra, 1994; Commission of European Community, 1998).

EDIFACT standards themselves do not lead necessarily to a plug and play solution for inter-organizational EDI connections, particularly in construction. The message content, the meaning of data within the message structure, has to be agreed by the interacting partners. SUMMIT will detail the content of the most important EDIFACT messages for the supply chain for prefab house systems, connecting the project manager (or other client's representative), the contractor / manufacturer, and suppliers/subcontractors. Thus, construction firms aiming to implement an EDI-based information flow will only be required to specify concrete instances of the detailed defined messages. The messages analyzed in SUMMIT are depicted in Figure 2. Further description of SUMMIT results regarding EDI and EDIFACT can be found elsewhere (Almeida et al 1998; Rabe et al 1998).

SUMMIT will also analyze the portfolio of commercially available EDI software and evaluate them against the requirements of the detailed EDI messages and their price range.

Table 1: EDIFACT Messages analyzed in SUMMIT

Business Transaction			
CONNIT	*Invitation to tender*	CONEST	*Establishment of contract*
CONTEN	*Tender*		
Materials Management			
PRICAT	*Price/sales catalogue*	REQUOTE	*Request for quote*
PARTIN	*Party information*	QUOTE	*Quote*
PRODAT	*Product data*	ORDERS	*Purchase order*
QUALITY	*Quality data*	ORDRSP	*Purchase order response*
ORDCHG	*Purchase order change*	DESADV	*Dispatch advice*
DELFOR	*Delivery schedule*	RECADV	*Receiving advice*
DELJIT	*Delivery Just In Time*	INVOICE	*Invoice*
Finance/Accountancy			
CREADV	*Credit advice*	FINCAN	*Financial cancellation*
PAYORD	*Payment order*	FINSTA	*Financial statement*
DEBADV	*Debit advice*		
Other fields			
PROTAP	*Project tasks planning*	CONDRO	*Drawing organization*
CONAPW	*Advice on pending works*	CONDRA	*Drawing administration*

3.2 SUMMIT developments in project management data

EDIFACT does not provide the solution to the whole spectrum of information exchange between heterogeneous IT applications within the supply chain. Most technical and managerial information exchanges will require other neutral format standards, particularly referring to product and process data.

In SUMMIT, it was perceived by the users, in this particular construction situation, the importance of complementing commercial and administrative data with project management data. Although there was an EDIFACT message specific for project scheduling and resources data exchange – PROTAP, it was decided that EDIFACT structure is not adequate to support the exchange of this type of data. Thus, the proposed solution was to apply developments in the Standard for the Exchange of Product Model Data – STEP, in AP225 and AP228, and particularly regarding the developments in the Building Construction Core Model (BCCM). The idea was to complement EDIFACT files with product/process data in standard format, i.e. embed the EDIFACT data structure with STEP structure. However, the analysis into this standardization area demonstrated that very few developments were made regarding project management data, and that current state-of-the-art would not support a pragmatic approach, a requisite for the user-driven type of project. RoadRobot was an exception in the standardization process, but little work had been developed afterwards. Moreover, it was also concluded that developments in STEP were moving slowly, and particularly developments in the BCCM had stopped, and thus little contribution could be made in this area.

In order to overcome the problem with project management data interchange between heterogeneous applications, SUMMIT envisages to use the developments made so far in the International Foundation Classes (IFC) version 1.5, of the International Alliance for Interoperability, to be actively involved in existing IFC

3.0 projects in the Project Management AEC domain, and contribute to the definition of Project Management IFC 4.0 requirements. In particular, SUMMIT will focus on the processes of construction scheduling.

According to the IFC Specifications (IFC, 1997a), the construction scheduling process creates a construction schedule using the objects across the IFC Model. In general, construction schedules will be developed through the analysis of the Task objects and Resource Use objects created when developing the Cost Estimating, and aggregating them into Construction tasks at the appropriate level for scheduling. However, this process must consider the size and complexity of the model. In situations where there is no cost estimating, the construction scheduling process will be different, implying a query to the shared project model. The objects found will be used as the basis for developing construction tasks. In both situations, time duration of the tasks will be estimated and construction sequences will be identified. The construction schedule is then created and analyzed, and after completion of the schedule, dates will be embedded in the IFC Model.

SUMMIT will not cover the full development cycle of the IFC (IFC 1997b). Indeed, due to time and resources constrains, only certain stages are covered. Thus, SUMMIT is working together with other existing projects in order to advance the Stage 2 – Specification, of the development cycle, regarding construction scheduling, on IFC 3.0. It will contribute to:

1. Enhance the usage scenario of construction scheduling, bringing specific requirements of the process of project management of prefab houses;
2. Detail the process model for the construction scheduling process;
3. Define the scope of the construction scheduling process;
4. Specify and enhance the IFC Object Model for construction scheduling;
5. Specify and detail Type definitions and Attributions;
6. Define Exchange classes related with construction scheduling classes.

SUMMIT will also contribute to Stage 1 of IFC 4.0 in the same domain. In this process, SUMMIT will suggest and propose new processes related to project management domain to be developed in the IFC 4.0 release.

4 Conclusions and acknowledgements

Building and construction industry should also concentrate on other areas of information integration rather than design, specially on those related with the automatic data flow of planning, control, scheduling, resources, materials, costs or general business and management information between firms. In an open market as we find today, integration of data has proved to be a requirement for substituting and improving with reliability and performance the manual or repetitive procedures.

The use of standards in the modelling process can help to proceed towards automated and integrated construction sites, integrating the actors in the different levels of participation in the manufacturing and business processes, both exchanging data among applications and sending messages for control of the process. Standards like STEP, IAI/IFC and UN/EDIFACT are examples of those that can contribute positively for the intent. The results achieved during the RoadRobot and SUMMIT projects stress these conclusions, based on experiences executed under real conditions. However, whether these systems are implemented in the real world is not just a technological problem (Grilo 1998).

We would like to thank, without exception, all the partners working in the RoadRobot and SUMMIT projects' consortium and, in particular, we acknowledge the European Commission by the financed budget and its support and trust in our ideas and developments.

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210 KNOWLEDGE-BASED PRODUCT DATA SERVER FOR CONCURRENT ENGINEERING

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Abstract

Many requirements to product data management for concurrent engineering can be most efficiently satisfied through the application of advanced client/server architectures together with appropriate knowledge-based methods. This paper outlines the basic design considerations for a knowledge-based product data server and suggests a development approach on the example of a prototype server implementation realised in the domain of architecture, engineering and construction (AEC).

Keywords: concurrent engineering, knowledge-based system, product data management

1 Introduction

State-of-the-art product data management (PDM) and CAE software for AEC involve sophisticated problem solving algorithms as well as high-level database management functionality. With the emerging IFC project model (IAI, 1997), supported by most established CAD vendors, the use of a standardised building model as basis for application interoperability and co-operative work is rapidly taking shape. Nevertheless, IT environments in AEC are still limited to data exchange on the basis of e.g. STEP physical files (ISO 10303-21 1994), or to data sharing using one global product model implemented on top of a general-purpose relational or object-oriented database system. Applications making use of product data technology methods are mainly realised on the basis of the object-oriented programming paradigm, typically in the C++ programming language. However, as outlined in table 1 below, the general demands of concurrent engineering methodology (Prasad 1992; Scherer 1998) impose several additional requirements to product data management in building construction beyond integration and simple data exchange which can be tackled more efficiently with the application of advanced knowledge-based methods in product data management server software.

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Table 1: Concurrent engineering issues requiring knowledge-based solutions

Basic Concurrent Engineering issues	Related PDM features	Appropriate knowledge-based solution methods
Collaborative work of physically distributed teams	• Distributed client/server architectures	• Advanced agent-based communication paradigm
	• Comprehensive data access and retrieval functions, providing just-in-time information	• Search engines Search agents
	• Continuous product model evolution	• Dynamic object evolution and classification methods
Co-operative problem solving	• Information sharing • Inter-model-operability	• Knowledge-based model mapping methods
Concurrency	• Multi-user access to product data	• Multi-agent architectures
	• Availability of local view models together with methods for effective model transformations	• Knowledge-based model mapping methods
	• Consistency checking	• Rule-based agents
	• Change and version management	• Model matching and merging methods
Simulation, monitoring and forecasting	• Advanced simulation tools	• Agent technology • Probabilistic reasoning • Cased-based reasoning • Learning algorithms etc.

Many of the above features would be embedded in advanced client applications armoured with deeper engineering knowledge than the scope of a PDM server would allow, but there are also several issues that require inter-discipline problem solving and are therefore better suited for server-side solutions. Tasks that would typically be dedicated to advanced server-side tools are e.g. model mapping and matching (Khedro et al. 1994; Scherer and Katranuschkov 1997), building code services (Han et al. 1999), information searches in the full project space (Scherer 1998b) etc. Such tasks are too complex to be satisfied on the basis of one single IT paradigm. Therefore, what is needed is a *hybrid approach* combining traditional object-oriented methods with advanced AI problem solving and representation techniques within a flexible client-server architecture. Moreover, the architecture of the PDM server itself has to be chosen in such way that a uniform interface to client software is achieved, conforming to a commonly acknowledged modelling methodology, such as STEP (ISO 10303-1).

Based on these objectives a PDM server has been developed and implemented for the IFC project model, release 1.5 (IAI 1997). The prototype environment includes client applications based on Autodesk's Architectural Desktop, a finite element structural analysis program, a foundation design expert system, a knowledge-based construction simulation system for geotechnical works and a facility management information system (Scherer 1998a; Katranuschkov and Hyvärinen 1998).

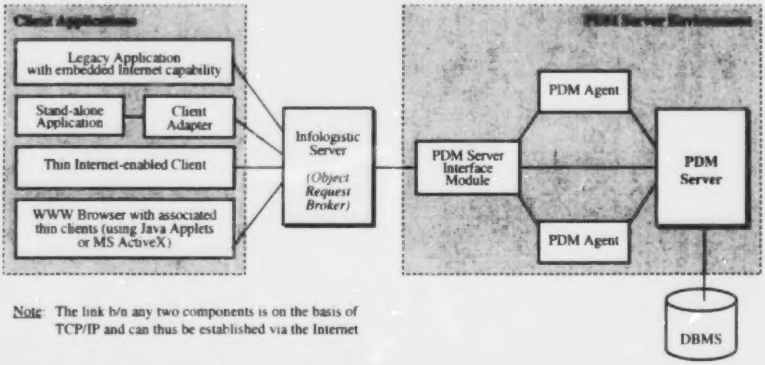
2 Client/Server environment architecture

Client/Server solutions based on TCP/IP and making full use of the Internet are doubtlessly most suitable for distributed project development, typical for the virtual enterprise in building construction.

There are quite a few different architectures that can be envisioned for a concurrent engineering environment based on the client/server communication paradigm. On the client side a variety of tools have to be supported, as shown on the left side of fig. 1. On the server side, the following realisation alternatives can be envisioned:

1. **All-in-one PDM server**
   This is, conceptually, the simplest possible server design. It has the benefits, but also the drawbacks of not being dependent on any other services. In order to satisfy fully the requirements of concurrent engineering, such server implementation must embed several features which go far beyond product data management functionality, such as process and workflow management, actor authentication, secure communication etc. Such features make the server implementation very complex and consequently extremely difficult to achieve in practice. On the other hand, if such implementation concentrates on typical PDM tasks, it can still be useful even without the support of all required issues, provided that an appropriate work discipline is maintained within the project team.
2. **PDM Server – DBMS**
   This alternative is very similar to the above, the main difference being in the use of a comprehensive commercial DBMS interfaced through a standardised data manipulation language like SQL, OOSQL, or through ODBC requests.
3. **Information Logistics Server – PDM Server Interface – PDM Server – DBMS**
   In this approach, full concurrent engineering support is achieved with the help of an Information Logistics Sytem (ILS) used as front-end server. The ILS encompasses: (1) an Object Request Broker that can identify among several possible servers the one responsible for answering an incoming client request (remote procedure call) and then forward the request to that server, (2) realisation of secure synchronous and asynchronous communication, and (3) identification and authentication of the issuing actor and/or software application (Wasserfuhr und Scherer 1998). With such architecture, all requirements to IT supported concurrent engineering can be satisfied, if a set of dedicated servers for comprehensive process, document and product management are available.
4. **ILS – PDM Server Interface – PDM Agents – PDM Server – DBMS**
   This is an enhancement of the architectures described above, allowing also intelligent server-side components to be integrated as automated software agents into the system. Such intelligent agents can accomplish more sophisticated server-side tasks like automated change recognition, notification of actors for possible conflicts, performing of certain well-defined automated services like cost estimation for prefabricated elements, automated model mapping depending on the state of the data etc. Therefore, in our opinion this alternative offers greatest advantages for concurrent engineering work in AEC projects.

The last alternative, shown schematically on fig. 1 below, has been actually used in the developed prototype, described in more detail in the following sections. Due to the prototype state of the development the application of a commercial DBMS was avoided for convenience.


Client Applications
Legacy Application with embedded Internet capability
Stand-alone Application
Client Adapter
Thin Internet-enabled Client
WWW Browser with associated thin clients (using Java Applets or MS ActiveX)
Infologistic Server
(Object Request Broker)
PDM Server Environment
PDM Server Interface Module
PDM Agent
PDM Agent
PDM Server
DBMS

Note: The link b/n any two components is on the basis of TCP/IP and can thus be established via the Internet

Fig. 1: Advanced multi-tier client/server environment configuration

3 Knowledge-based product data representation

The realisation of PDM functionality is nowadays most commonly achieved on the basis of sets of loosely connected tools, or, at the high-end, with the help of integrated PDM servers using the object-oriented programming paradigm. However, according to our opinion, object-oriented methods alone are not powerful enough for the implementation of many advanced tasks required for efficient concurrent engineering support. Therefore we propose the use of a *hybrid approach*. In this approach the underlying modelling framework of the environment is based on the ISO STEP methodology, enhanced through the use of EXPRESS-C (ISO/TC184 1994) as a common modelling language for all supported data models. To enable coherent use of both the object-oriented paradigm based on the EXPRESS-C specification and knowledge-based methods applied in several product data services, such as model transformations, model matching, complex queries and assertions on the basis of generic templates etc., the representation of the product data models in the PDM server is done according to the *frame-based modelling paradigm* (Russel and Norvig 1995).

The suggested frame-based representation parallels the conceptual model schemata specified on the basis of EXPRESS-C. *Frames* can incorporate all object-oriented features of EXPRESS-C entities, such as inheritance, state (attributes) and behaviour (operations), but allow also to vary dynamically the number and type of their attributes (important for object evolution methods), to define different properties of the attributes themselves (important for dynamic object classification rules), as well as to associate rules to different frame structures. *Rules* are defined separate from the data and methods captured within frames, and can be used for run-time binding of variables to modelling object instances. This enables their use for information retrieval purposes in applications that do have knowledge of the model schema, but not necessarily of the particular model instantiations. Rules are triggered through the execution of ASSERT and QUERY functions from the body of the object-oriented server methods. Thus, rule-based reasoning can be seamlessly integrated in the "normal" object-oriented requests of a client application to the PDM server, as shown on the simplified example in fig. 2.

TC_Model extension in EXPRESS-C:

```
ENTITY TC_MODEL SUBTYPE OF (IfcRoot);
...                              -- attribute specification
(* versionStatus: StatusEnum;    -- inherited from IfcRoot *)
Operations                       -- EXPRESS-C method specification
   match (compVersion: TC_MODEL);
...
END_ENTITY;
```

When a modified version of an instantiated product model `M1` is checked in at the PDM server and its status is set to "proposed", e.g. by executing a remote procedure call from a client application like:

```
     M1.setAttribute (Name:"Status", Value:"proposed") *)
```

the following rule will be triggered automatically, allowing a separate agent process to determine all changes done to the model and to notify subsequently the affected actors:

```
IF (the 'versionStatus of ?m is 'proposed) ; ?m is automatically bound to
   (the 'projectID of ?m is ?id)           ; the model instance M1.
   (?n is in 'TC_MODEL)                    ; Gets all 'active' instantiated
   ((the 'projectID of ?n) = ?id)          ; model versions with the same
   (the 'versionStatus of ?n is 'active)   ; projectID on the server.
THEN
   (the 'versionStatus of ?n is 'frozen)
   (exec.operation 'match (oid:?m inParams:(?n)))
```

*) Note: The syntax of client requests is simplified here and in all subsequent examples for convenience.

Fig. 2: Triggering a rule-based method from a client application

In this example, `exec.operation` is used to invoke the object-oriented method "match", thus allowing to combine rule-based and object-oriented techniques.

`match (oid: ?m inParams: (?n))` is the method that will be applied consecutively to model `M1` and any other model `N`$_i$ satisfying the above rule. However, it will in turn trigger forward and/or backward chaining rules during its execution, switching seamlesly between object-oriented and rule-based processing techniques.

The actual implemented rules in the PDM server for the above example are somewhat more complicated, but without any principal difference. Simiiar rules are applied for other possible model states, allowing the PDM server agents to react automatically to various changes in the enviornment.

4 Architecture of the knowledge-based product data server

The outlined representation paradigm allows the development of a server architecture that very much resembles that of a typical knowledge-based system as shown in fig 3. However, in contrast to expert systems, designed to assist engineers in the solution of specific problem solving tasks, the goals of the knowledge-based methods in the PDM server are to react to general-purpose, yet complex queries and assertions, and to adapt dynamically to a variety of changes in the product models resulting from the concurrent, simultaneous work of the separate actors in a project team.

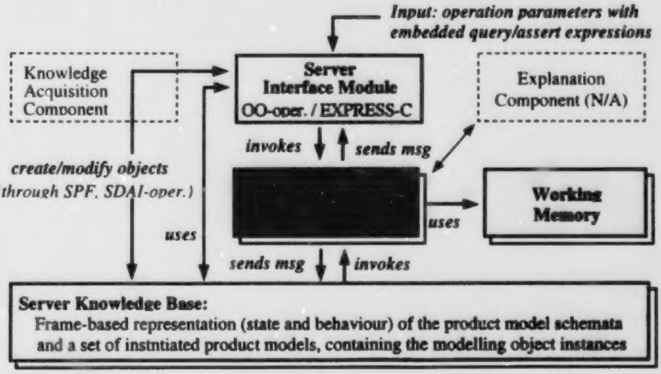

Input: operation parameters with embedded query/assert expressions
Knowledge Acquisition Component
Server Interface Module
OO-oper. / EXPRESS-C
Explanation Component (N/A)
invokes
sends msg
create/modify objects (through SPF, SDAI-oper.)
uses
Working Memory
uses
sends msg
invokes
Server Knowledge Base:
Frame-based representation (state and behaviour) of the product model schemata and a set of instntiated product models, containing the modelling object instances

Fig. 3: Knowledge-based server architecture

The main component of the proposed server architecture is its *knowledge base* containing a set of predefined data model schemata, as well as one or more product models associated with each model schema and representing the separate work spaces and views of each actor on the designed building product. Each data model schema in the knowledge base is organised in a frame structure, as described in the previous section, and contains exclusively *class frames*, roughly corresponding to the entity structuring given in the EXPRESS-C schema of the model. The instantiated product models, on the other hand, contain only *instance frames* with inherited attributes and behaviour from the respective underlying data model schema. All frames can act both as "normal" objects, responding to messages from the outside and/or from other objects, as well as to participate in rule-based queries and assertions. The knowledge base can accommodate also overall rules similar to the global rules in EXPRESS.

The *interface module* has the task to resolve properly the requested operations by a remote client, and to activate the appropriate server object methods responsible for the execution of the client requests. All incoming requests and result responses are also based on the formal EXPRESS-C specifications in the data models, regardless of the particular internal server method used (pure object-oriented or knowledge-based implementation). In this way, the interface module allows to hide from the users and clients the implementation details of the server, which simplifies greatly client implementation.

The actual processing of a request is done in the following steps: (1) the request is parsed, the data are transformed to an appropriate internal format and the specific task is identified; (2) except when explicitly given, the expected server load is judged and the task is classified as a synchronous, high-priority asynchronous or low-priority asynchronous (heavy-duty) task and is then queued respectively; (3) when the task is awaked for execution, an appropriate server method is chosen and activated, and (4) the results of the performed method(s) are stored on a solution blackboard and in the respective data model in order to be available for other server modules, and are at the same time transformed in a respective server response to the calling application.

The *reasoning agent* has the task to perceive changes in the environment and to react to such changes with appropriate goal-driven, utility-driven or reflexive actions (Russel and Norvig, 1995). Within the PDM server architecture each reasoning agent is invoked by an object-oriented method whenever a knowledge-based function is addressed. This can be done explicitly, by executing a respective operation, such as:

```
IfcRelUsesProducts.find (
   searchExpr:(FOR ?X DO (?X HAS AT LEAST 2 RelatedObjects)))
```

or happens automatically, when the state of an attribute monitored by a demon method is changed, as shown e.g. in fig. 2 for the `TC_MODEL` operation `setAttribute`.

The general syntax of a search expression in EBNF format is

(FOR { $?X_i$ }* **DO** (<*searchTemplate*> { **AND** | **OR** <*searchTemplate*> }*))

where $?X_i$ is a free variable, bound dynamically to the set of values satisfying the search, and <***searchTemplate***> is used for executing a predefined query, such as subclass membership, maximum cardinality, equality, attributes satisfying a given condition etc.

Typically a reasoning agent will retrieve the required data from the knowledge-base together with the appropriate reasoning rules and will place them in the working memory of the server. After that the inference process on the retrieved data and rules is started, and, on its completion, the result is returned to the calling method. Currently, the server implementation incorporates an inference engine including forward and backward chaining as well as different search algorithms. However, these methods can be extended using the same component architecture.

The remaining (dashed-box) components shown in fig. 3 are given only for comparison with typical expert system architectures. An explanation component is difficult to envision for a server software, and a comprehensive knowledge acquisition component has been beyond the scope of the server implementation, although new knowledge can (and is) continuously introduced in the knowledge base through respective "assertion" requests.

5 Knowledge-based product data services

The Application Programming Interface (API) of the prototype implementation of the proposed knowledge-based PDM server encompasses more than 40 operations that can be used by a remote client application. Most of these operations are based on SDAI (ISO 10303-22 1996) or support data exchange functionality on the basis of STEP physical files (ISO 10303-21 1994). However, in order to provide an enabling infrastructure for concurrent engineering, several sophisticated services involving knowledge-based operations have been specified as well. Such services include model mapping, model matching and model merging, conflict recognition, generic consistency checking etc. They have all been prototyped on the basis of the distributed client-agent-server architecture described in the previous sections.

To illustrate the approach here we shall consider a simple practical example involving model mapping. The realisation of the other knowledge-based services adheres in principle to the same overall methodology.

5.1 Model mapping

Any application needs to extract a view from the product model, and the transformation from the product model to such view is unique to the application (Clancy 1985). The goal of model mapping is to enable such model transformation - in the ideal case automatically, without any user interaction.

Model mapping involves the conversion of one modelling representation to another without awareness of the context, i.e. already existing local data in the target model (Scherer and Katranuschkov 1997). The mapping process is performed on the basis of a formal specification of all necessary translations on class level, and includes full or partial transformations of the data instances according to this specification. As a basic interoperability problem in product data based environments, model mapping has been intensively investigated in the last years, and several formal mapping languages and implementation techniques have been proposed (Liebich et al. 1995; Katranuschkov and Scherer 1996). However, whilst all proposed generic approaches are quite useful for creating full new views or versions of a product model, they are complicated to use when context-dependent transformations are required because all generic specifications are done on class level and are therefore static, i.e. they cannot reflect the changes in the environment. Such context-dependent transformations can be realised much easier with the help of the suggested knowledge-based approach.

To focus the discussion, let us consider the following example: "mapping from an IFC product model to a foundation design system".

The necessary input to the foundation design system is fairly simple. It is comprised roughly of the geometric and material properties of the ground plate of the examined building, the soil properties of the site, the points at which the overhead structure interacts with the foundations and the loads applied to these points. Though not very voluminous, this information is available in an IFC model in quite different form. Moreover, it is depending also on the specific instantiated context, i.e. the particular relations between the product data instances. The needed loads can for example be represented in IFC as support reactions of IfcWall and IfcColumn entities, stored in appropriate property sets*), but this is only valid for elements connected to the particular ground plate under consideration.

Such mapping conditions are extremely difficult to specify on class level, and the use of a generic implementation approach can lead to considerable computational time. On the contrary, with the help of the described knowledge-based query functions the same conditions can be easily specified with minimal user input and the mapping can be performed automatically by a mapping agent, whenever it detects that the necessary input data are available. In fact, the concrete realisation of the considered mapping example has required only 4 different knowledge-based queries, such as:

```
Obj.find
    (searchExpr:
       (FOR ?D ?V DO
            ((THE HasProperties OF Obj IS ?Y) AND
             (((THE Descriptor OF ?Y) = " NODE_REACTIONS" ) OR
              ((THE Descriptor OF ?Y) = " LINE_REACTIONS" )) AND
```

---

*) Such property sets are not elements of the current IFC project model specification. They have been used in the implemented prototype to enable the consideration of structural engineering software in the environment.

```
    (THE HasProperties OF ?Y IS ?Z) AND
    (THE Descriptor OF ?Z IS ?D) AND
    (THE ValueComponent OF ?Z IS ?V))))
```

Such queries may appear complicated, but their specification is straight-forward and, because of their expressive power, the full implementation of the mapping (in the Java language) is fairly simple – in this case just about 100 lines of code.

6 Discussion

Concurrent engineering requirements are not well supported in existing IT environments for AEC. One reason for that are the limitations of object-oriented technology which is used as basis in most known implementations. The hybrid approach proposed in this paper allows to overcome many of these limitations with the help of appropriate knowledge-based server-side tools. With such dedicated tools it is easy to implement various client adapters, with a GUI support for all needed PDM services.

The suggested knowledge-based architecture of the PDM server provides the following benefits: (1) separation of data structures from high-level rule-based data management knowledge, (2) encapsulation of knowledge-based methods within the procedural attachment of operations to the modelling objects, enabling the use of uniformly defined function calls from the outside, (3) full consistence with the conceptual object-oriented modelling approach. On the basis of this architecture, a comprehensive PDM environment incorporating different building design services as suggested e.g. in (Han et al. 1999; Turk et al. 1998 etc.) can be envisioned.

7 Acknowledgements

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211 LEXIS — AN AEC INDUSTRY LANGUAGE

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Abstract

In the context of a strategy for information management in the building and construction industry, this paper identifies and briefly examines the relationship between key industry stakeholders. Accepting the fundamental role of a project decision, it examines the flow of information between these decision-makers as a first step in developing an industry wider language. Finally, it discusses Lexis, a language being developed within CSIRO-BCE, and how it addresses these requirements.

Keywords: Language, project information exchange, project decision-making

1 Introduction

The building industry is under increasing pressure to improve the quality and value of its product, the efficiency and effectiveness of its processes and the accountability of its decision-makers. At the same time buildings are getting larger and more sophisticated[1], and building technology and material science becoming increasingly complex and subject to error in specification, installation, operation, and maintenance. These, in turn, are leading to larger and more specialised project teams whose members have increasingly narrower views of the project and of their respective responsibility towards it. The take-up of communication and computer technology is adding yet another dimension to the problem. While holding out the potential to address the above it does so by introducing yet more requirements. 'Data sharing' – entering data once and

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[1] The Australian Procurement Construction Council suggests that up to twenty specialist skilled subcontractors may be employed on a residential housing project and up to 200 specialist skilled subcontractors may be employed on a major construction site (APPC, 1997).

Durability of Building Materials and Components 8 (Volume Four). *Edited by M.A. Lacasse and D.J. Vanier.*
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having it accessible to all who require it – will save time, facilitate coordination, and reduce the potential conflict and confusion caused by the existence of multiple copies. However, doing so will introduce the need for all members of the project team to use an agreed way of identifying and describing the objects about which data is being shared. In fact, because projects do not occur as isolated events, such an agreement is likely to have to be industry wide.

Further, if the experiences in other industries is relevant, the effective use of IT will require the building industry to undergo fundamental structural change. In banking and finance, in the retail industry, in the introduction of credit card, traditional competitors found it necessary to come together to cooperatively establish the necessary infrastructure before returning to compete on new level. As The Financial Review notes, "fierce rivals such as Coles Myer Ltd, Woolworths Ltd and Franklins Ltd come together for the first time to discuss using high technology to improve the industry's structure and increase its competitive edge." (Carr, 1997)

Clearly, the problem facing the building industry is as much cultural as it is technical. And given its size and nature, change is likely to occur over an extended period of time – as individuals, and individual organisations, see direct, short term benefit. While responsibility for a significant proportion of this change can be left to individual self-interest, responsibility for overall integration, and developing and maintaining a common language, must be addressed by the wider industry.

This paper briefly examines the roles of key industry stakeholders as a basis for developing a strategic framework for managing information in the building and construction industry. It then considers the flow of information between these decision-makers and begins to draw out concept that a common language will have to address. Finally Lexis, a language being developed by CSIRO-BCE, is examined and a possible approach to the development of an internationally harmonised language is raised.

2 Stakeholders

There is insufficient room here to discuss the development of the proposed information management and decision support system. Suffice it to note that any initiatives in this regard must identify and respond to the need of:

- *Project decision-makers* - generalists (facility owners and financiers; designers, documenters, builders and demolishers; asset managers and maintainers) whose decisions and actions determine the quality and value of the end product.
  Focused on a project with its time and cost constraints, these stakeholders are unlikely to be in a position to keep abreast of changes to the industry knowledge base in more than a few areas of special interest. Being in a position of not knowing what they don't know, these decision-makers will need proactive access to project and external reference data.
- *Industry reference library managers* – specialists (building regulators and researchers, through manufacturer's technical and sales staff, to office

manager and librarian in consultant's offices) with an interest in and in-depth understanding of their respective domain(s).

(Industry reference library data is defined as any information residing outside of a particular project but intended for inclusion. This material ranges from building codes and standards, through research findings, manufacturers' literature, specification text and construction details, to performance bench marks and office procedure manuals.)

While dealing with different material and driven by different motives, these stakeholders have a common objective – having their material in front of the project decision-maker in a form and at a time that facilitates understanding and application. The fact is that each of these managers wants to 'speak' to the same project decision-maker – who is unlikely to have either the time or desire to learn a host of different protocols – argues strongly for the cooperative development of agreed communication conventions.

- *IT resource providers* - developers and marketeers of the communications, data access and decision support tools used by the other two stakeholder groups.

The more precisely the first two groups can define their information needs, the easier it will be for the IT provider to provide cost efficient, application specific, resources. Unfortunately, to date, neither group has been a particularly good in this regard. Hopefully the proposed information framework and its common language will help to remedy this situation.

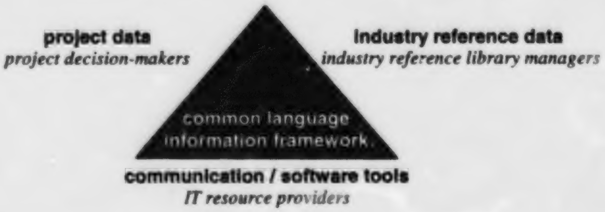
project data
project decision-makers
industry reference data
industry reference library managers
common language
information framework
communication / software tools
IT resource providers

Fig. 1: Stakeholders and resources

3 Project decision-making

Regardless of the facility, its stage of development, contractual arrangements between the stakeholders or the technology used, to advance the work someone has to take a decision or action (DA). Who takes it and whether it is good, bad or indifferent, is project specific and of concern only to other members of the project team. In this context, the role of the proposed information and decision support system is limited to ensure that the decision-maker has efficient, effective access to relevant input (project and reference library data) and that the output is available for subsequent DAs.

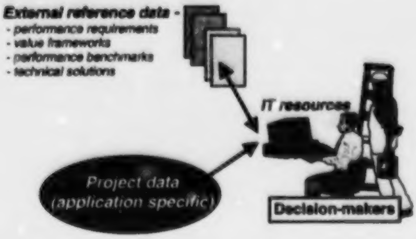

Fig. 2: Project decision/action set

As already noted, because the decision-maker is unlikely to be aware of what is available or of its relevance to the work at hand, such access must be proactive. That is, the project decision-maker who knows the project, it problems, issues, and priorities but lacks currency with regard to the industry knowledge bases, must be able to describe the circumstances of the project in such a way that the reference library managers, who have the necessary currency, can confidently respond with application specific information that is in a form that can be readily understood and applied with minimum reprocessing.

Project decisions, however, are rarely taken in isolation. The procurement and management of a facility involves hundreds of people taking thousands of DAs over extended periods. While each decision-maker understands the project and acts from a unique perspective, the fact is that he or she must communicate and coordinate their DAs with others. While there doesn't appear to be precise demarcation, this communication and coordination falls:

- *within a project phase* – where time and space allows one member of the project team to take a decision and to draw it to the attention of the others who can assess its implications for their respective areas of concern. Conflicts can be identified and mutually satisfactory solutions negotiated.

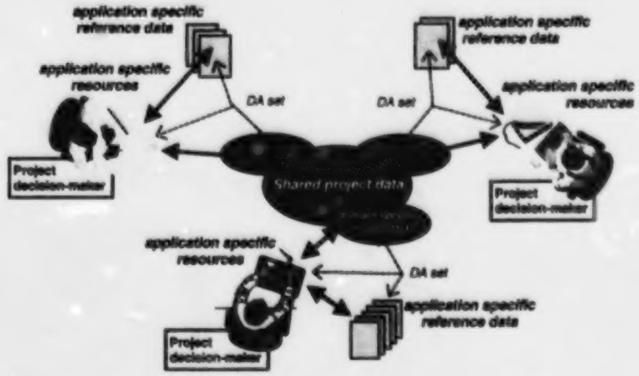

Fig. 3: Domain views and decision sets

For example, during the design phase, several decision-makers might seek to manipulate a wall according to their respective area of responsibility. The space planner might be concerned with its location and surface. The cost controller might be concerned with its impact on the capital cost budget. And, given the environmental and users conditions, they might wish to calculate its useful life in order to assess its impact on the recurring cost budget. The thermal engineer might be concerned with its location (as it determines the size of a space to be environmental conditioned), its thermal mass and thermal transmission. The structural designer, wishing to use part of it in the building's structure, might be concerned with its location and structural capacity.

As Fig.3 suggests, some data will be of concern to several decision-makers (eg wall identification, size, shape, location) and some will be of concern only to one individual (eg surface, colour, capital cost, recurring cost, thermal mass, thermal transmission, structural capacity). Whether data is to be shared or held exclusive to an individual will vary with the project and the responsibility of the project team to determine. Again, the role of the proposed information system is simply to facilitate the process – by providing a means of identifying specific units of data and associating them with one or more stakeholders.

- *between project phases* – where, due to time and space, decision-makers are unable to enter into direct negotiations. Under such a circumstance, one decision-maker will take a DA and inform another of the outcome (traditionally this has taken the form of a proposed solution). The need for the initial decision-maker to offer a solution remains, but this must be supported by an option to pass assumptions and/or performance requirements.

  Further, where the outcome of the latter decision-maker's DA is critical to the former, a method of compliance monitoring is required.

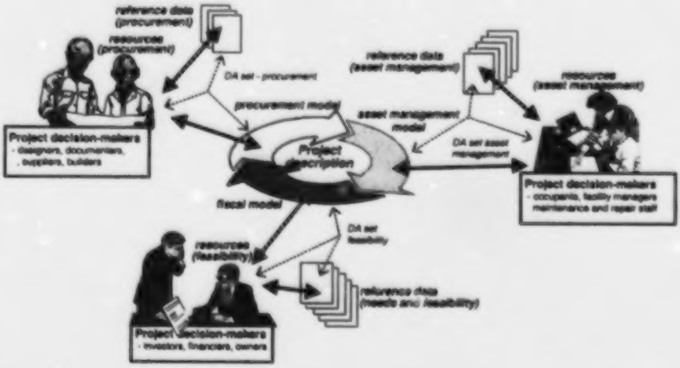
reference data (procurement)
resources (procurement)
DA set - procurement
reference data (asset management)
resources (asset management)
procurement model
asset management model
DA set asset management
Project description
Project decision-makers
- designers, documenters, suppliers, builders
Project decision-makers
- occupants, facility managers maintenance and repair staff
fiscal model
DA set feasibility
resources (feasibility)
reference data (needs and feasibility)
Project decision-makers
- investors, financiers, owners

Fig. 4: Communication and compliance monitoring between phases

For example, during project feasibility studies, the financial planner will make assumptions about income and expenditure based on the facility being able to attract and retain a certain class of tenant. The Property Council of Australia (PCA) has formalised this in the form of their Office Quality Grade Matrix (PCA, 1997). Among other things, in relation to lifts, they identify the maximum waiting time, minimum capacity, and ride quality. Failure to meet this performance profile could jeopardise the financial viability of the project through the down grading of the facility and thereby its ability to attract the desired tenants. Rather than waiting until the project is finished and occupied, once the lift strategy has been established (numbers off, capacities, speeds, ...) the financial planners should be provided with a compliance report setting out the 'projected performance' in each of the nominated areas. Once the lifts are installed and operating another compliance report, setting out the 'achieved performance' figures, should be issued. Further, once the facility is in operation, the 'achieved performance' figures should be checked against what was initially projected and a post-occupancy evaluation should be undertaken to ascertain the 'valued performance' (an assessment of the relative worth of various aspects the lift strategy in relation to other PCA performance objectives).

In addition to assuring the quality and value of end-product, such a compliance monitoring system will enable 'self-certification' of compliance with local building codes and regulations.

To facilitate the levels of communication discussed here, there is a need for a common framework within which information can be reliably accessed and processed by individuals, and passed between project stakeholders – within a project phase and over the project life cycle.

This framework, and its supporting language, must involve all sectors of the industry, cover both written and electronic information, and deal with subjective as well as objective issues.

4 Lexis - a common language

Language – any set or system of such symbols as used in a more or less uniform fashion by a number of people, who are thus enabled to communicate intelligibly with one another. (The Macquarie Dictionary, 1985)

While each decision-maker sees the project from a different perspective - has different objectives and contractual responsibilities – the fact is they must realise their respective goals through the manipulation of a common and relatively limited kit of parts. Lexis is intended to identify, describe, and attribute the objects in this 'kit'.

This section examines these objects, including how their data changes over the project life cycle, in order to determine what should or should not be included in the proposed system.

4.1 Object identification

Object – a functionally identifiable unit.

System – an *object*, composed of two or more *objects* (operational, spatial, physical), that together serve a characteristic function. Systems can contain other systems.

Component – an *object* with a characteristic function within a *system*. A *component* can belong to one or more *systems*.

View – an aggregation of objects and object attributes relevant to a particular process (decision or action).

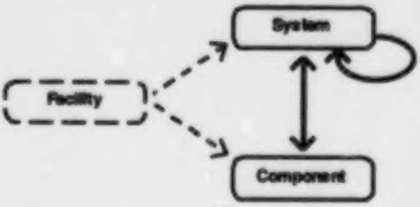

Fig. 5: Systems and components

Depending on the perspective of the decision-maker, a *system* can be a *component* and vice versa. To illustrate, an airport is a *facility*. So too are its terminal buildings, parking areas, runways, fuel dumps, and fire stations. Whether these facilities are seen as systems or components of systems will depend on the issue(s) under review. That is, to the regional planner the airport is a *component* of the city. To an airport manager it is a *system* in which the terminals, parking and rental car areas, runways, hangers, fuel dump, and fire stations are *components*.

This system/component relationship includes the building shell and services. To the designer, a wall is a *component* of the building. To the builder it is a *system* – composed, for example, of studs, plates, bridging, nails, plasterboard, edge beading, joint tape and plaster.

In other words, on a decision by decision basis, the project decision-maker will determine whether an object is a system or component. With reference back to Fig. 3 and 4, if these decision-makers use a common pool of objects to construct their respective views, they can each act from within their respective decision-sets confident that any value(s) they assign to an object attribute can be applied in a different domain. Where two stakeholders enter different values, any conflict will be immediately flagged and a mutually acceptable value negotiated.

This *object* (kit of parts) *view* (decision-maker) relationship is the basis upon which Lexis is being developed.

4.2 Lexis components

Lexis Core –an industry agreed set of *objects* (systems and components), including their associated attributes and relationships. The *Core* provides a pool of objects from which domain groups construct their respective *Views*. It is the 'kit of parts' referred to above.

Lexis View(s) – are aggregations of *objects*, *object attributes* and *object relationships* drawn from Lexis Core that model some aspect of a facility, eg capital cost, recurring cost, energy, construction management.

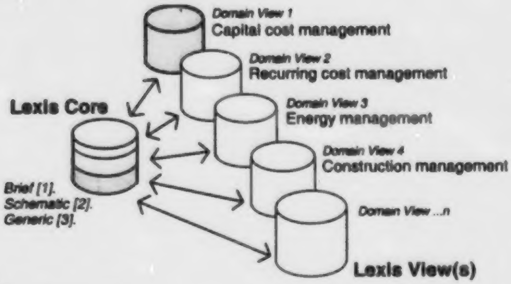

Fig. 6: Lexis components

4.3 Core objects

The objects identified here are indicative only. The final set will be determined in consultation with industry decision-makers – ensuring that the objects and object attributes are appropriate to their DAs.

4.3.1 Object classes

- **Operational objects:**

  Operational system - a set of goal-directed operational activities associated through a common objective and undertaken in support of the operational objectives of the organisation being accommodated in the facility.

  Operational component (setting) – a goal directed activity undertaken as part of an operational system.

  An operational setting might include –

  Actors – individuals, including their aids and/or appliances, involved in the activities of an *operational setting*.

  Furniture, equipment – objects, permanent fixed or brought in as required, that serve an identified function in the activities of an *operational setting*.

For example – the client might identify a school library as an *operational system* within which entering and leaving, checking out and returning books, searching the catalogue, periodical browsing, private and group study, are *operational settings*. Equally, the building regulator might identify the need for emergency egress as an *operational system* in which passing through doors, travelling corridors, and descending stairs are *operational settings*.

- **Spatial objects:**

  Spatial component – a notionally bounded three-dimensional volume.

  - *cell* - a notionally bounded three-dimensional envelope defining the extent of a micro-environment, eg shell (wall cavity), service (illumination ray diagram).
  - *activity space* - a notionally bounded three-dimensional envelope that defines the extent of an operational (*setting*) component.
  - *chamber* - a notionally bounded three-dimensional envelope, commonly defined by physical objects such as walls, within which one or more operational settings occur.
  - *zone* – a notionally bounded three-dimensional envelope, within which one or more spaces are aggregated through a common purpose.

- **Shell objects:**
  Shell system – a set of physical components associated through a common function of enclosing and sheltering facility occupants or activities.
  Shell component – a physical component or assembly of components that serves an identified function within a shell system.
- **Service objects:**
  Service system – a set of physical components associated through a common function of servicing a facility's occupants or activities.
  Service component – an object that serves an identified function within a service system. Service components include:
  - *nodes* – points in a services system or branch that processes a service substance. Node types include source, processor (monitor/control, treat, protect), and terminal.
  - *links* – a means of conducting a substance between nodes in a service system.

A service system may be *reticulated* (a service in which the substance is reticulated to the point of use) or *transported* (a service in which the substance is physically carried from one point (source) to another (terminal). Note, the terminal of a transported service can be the source of a reticulated service, eg. oxygen can be trucked to the site in cylinders and attached to a manifold where it is reticulated through the facility.

4.3.2 Object life cycle

With reference to Fig. 7, over the project life cycle, many of the objects identified above will undergo:

- ***attribute reassignment*** - A project brief [1] might identify an *operational system* 'a', containing two *operational settings 'b'* and *'c'*. One noise generating and the other noise sensitive. During schematic planning [2] the required noise reduction will be calculated and assigned to a notional shell object - *separator*. Once the physical relationship between the *operational settings* is established [3] – adjacent to one another and separated by a wall, or possibly across the corridor from one another and separated by two walls and a corridor – the sound reduction value of the separator can be reassigned to either the single wall and its finishes, or to the combination of two walls, their respective finishes and a 1200 mm air space.
- ***transformation*** - During design [3] other project decision-makers will identify and assign their performance requirements to the generic wall(s) identified above. This 'required performance profile' can then be used in a search engine to contact the relevant industry reference libraries for potential technical solutions. The candidate solution, offered by manufacturers and suppliers of walls or wall components, will have a 'projected performance profile' that each affected decision-makers will use to assess the implications it may have for their respective area of concern.

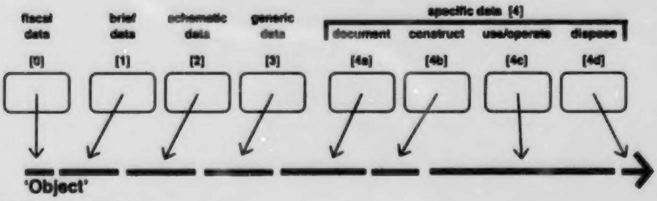

Fig. 7: Object data phases

Once the wall type has been selected the relevant manufacture/supplier, as part of its marketing strategy, might provide the:

- *documentation team* [4a] with a list of the materials and products out of which the nominated wall is constructed, construction details appropriate to the nominated performance requirements and units costs.
- *construction team* [4b] with delivery times and other data to enable electronic ordering, receiving, and payment for the nominated items.
- *asset management team* [4c], where appropriate, with data on how to operate, maintain, and repair the object.

In the same way, a manufactured product such as a water pump, moves from a generic object [3] with a required performance profile, to a specific one [4a] with an identified make, model and projected performance profile. Finally, during construction, it will become a specific object with make, model, serial/batch number, dates associated with its purchase, installation and commissioning, and an achieved performance profile.

The introduction of 'required/desired', 'projected' and 'achieved' performances provides the basis for quality control and compliance monitoring. Further, post-occupancy evaluation can tap the users' experience of the facility to establish a 'valued' performance of an object for use in preparing a brief for a subsequent project.

4.3.3 Object attributes

Cross-referencing the objects classes with their respective life cycles, establishes a matrix used to identify the objects and object attributes required to carry the concepts and/or data required by the various members of the project team.

This section offers a brief indication of the objects and their associated attribute sets.

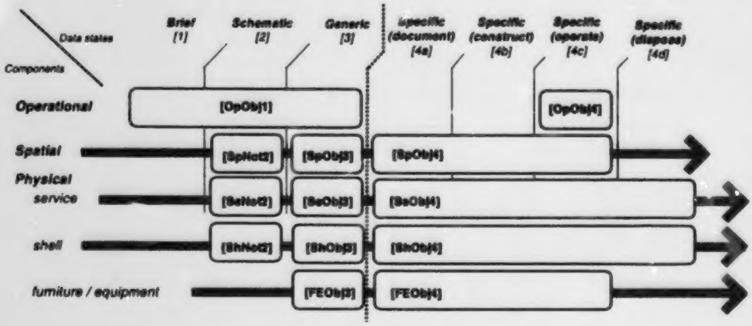

Fig. 8: Lexis data framework

***Objects and object attributes** (indicative only)*

Operational (setting) objects:-

Primary school library	
Browsing system	
Periodical display	[OpObj1]
Casual seating	[OpObj1]
Book access system	
Using catalogue	[OpObj1]
Accessing books	[OpObj1]
Private study system	
Work station	[OpObj1]
Book checkout system	
Check out counter	[OpObj1]
Librarian work station	[OpObj1]
Book return area	[OpObj1]

Operational (setting) object attributes:-

Identification
lexis id
project id
reference library id
Description
definition
geometry
position (location, orientation)
Performance
production rates
Need
environmental (from Actor and F&E needs)
shell
service
Impact
environmental (from Actor and F&E impacts)
shell
service

Spatial objects:-

Activity space	[SpNot2]
Chamber	[SpNot2]
Room	[SpObj3]
Corridor	[SpObj3]
Stairwell	[SpObj3]
Service riser	[SpObj3]
Zone	
HVAC zone	[SpObj3]
Fire zone	[SpObj3]

Spatial object attributes:-

Identification
lexis id
project id
reference library id
Description
definition
geometry
position (location, orientation)
Performance
environmental (sum of Settings in space)
Need na
Impact na

Physical (shell) objects:-

Separator	[ShNot2]
Wall core	[ShObj3]
110mm brick wall	[ShObj4]
75mm frame wall	[ShObj4]
Wall finish	[ShObj3]
paint finish	[ShObj4]
wall paper	[ShObj4]
cement render	[ShObj4]
set plaster	[ShObj4]
ceramic tile	[ShObj4]
Door	[ShObj3]
Window	[ShObj3]

Physical (shell) object attributes:-

Identification
- lexis id
- project id
- reference library id

Description
- definition
- geometry (object, maintenance access)
- position (location, orientation)

Performance
- Separation (acoustic, physical, fire, ...)
- Capacity (load bearing, ...)
- Resistance (abrasion, water, fire, ...)
- Cost (capital, recurrent)
- Embodied energy

Need
- environment
- shell (deflection, vibration, ...)
- service (supply, removal)

Impact
- environmental emissions ()
- shell (loading, ...)
- service ()

Physical (service) objects:-

Source	[SeNot2]
Existing service	[SeObj3]
Utility	[SeObj3]
Tank	[SeObj3]
Terminal	[SeNot2]
Tap	[SeObj3]
Fowler model AC632	[SeObj4]
Equipment	[SeObj3]
Plant	[SeObj3]
Processor	[SeNot2]
Link	[SpNot2]
Pipe	[SpObj3]

Physical (service) object attributes:-

Identification
- lexis id
- project id
- reference library id

Description
- definition
- geometry (object, service access)
- position (location, orientation)

Performance
- capacity (volume, flow rate, pressure, ...)
- resistance (abrasion, water, fire, ...)
- cost (capital, recurrent)
- embodied energy

Need
- environment
- shell (deflection, vibration, ...)
- service (supply, removal)

Impact
- environmental (emissions, noise, heat, odour, ...)
- shell (operating wt, shipping wt, ...)
- service ()

Fig. 9: Objects and object attributes (indicative only)

5 Lexis application

With reference to Fig. 10, this section illustrates the practical application of Lexis objects.

5.1 Brief

The client brief identifies an *operational system 'a'* containing three *operational settings 'b', 'c', 'd'*. The people and equipment associated with each setting is also nominated. *Setting* 'b' is noise sensitive (need_noise level) and 'd' requires equipment that is noise generating (impact_noise level).

5.2 Schematic

During schematic planning *settings* 'b' and 'c' are located in *space 'e'* and *setting 'd'* in *space 'f'*. At this point the design is not be sufficiently developed to establish the spatial relationships between these *spaces (rooms)* so the required sound reduction (performance_separation_sound reduction) is assigned to the notional *separator* 'g'.

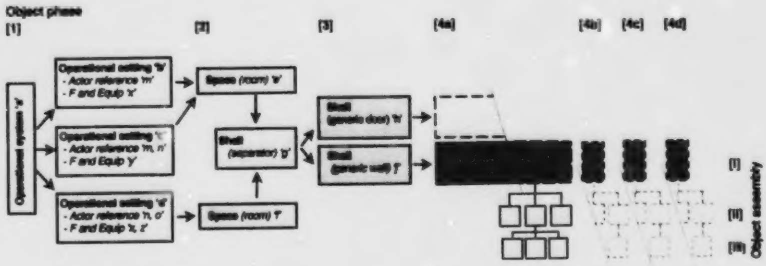

Fig. 10: Project data flow

5.3 Generic

As the design is resolved *rooms 'e' and 'f'* might be adjacent to one another (separated by a wall) or possibly across the corridor from one another (separated by two walls and corridor space). Respectively, the 'required' performance of the *separator* would be assigned to a *single wall 'j'*, or the combination of two walls and a corridor space.

This 'required' acoustic performance would be combined with other such requirements (eg. thermal insulation, fire rating, structural capacity, capital cost) to form the 'required performance profile' of the intervening walls and doors. This profile being used to search manufacture's reference libraries for potential solutions (this search tool is being developed by CSIRO under the name - Dynamic Data Directory). Each of the manufacturers' nominated solutions will have an associated 'projected performance profile' based on their product testing.

5.4 Specific

Once the particular wall type has been determined, the manufacturer might identify and specify the products and materials, and provide relevant construction details [4a]. To assist the builder, the manufacturer might supply costs and delivery details for the nominated materials and do so in a manner that, once the construction of the wall is scheduled, the ordering, shipping, and receiving of the materials and the subsequent invoices and payments can be managed automatically (electronic commerce). Any change to the schedule would automatically change the order/deliver dates [4b]. As appropriate, information might also be supplied to the facility manager to operate and maintain the components [4c] and to the demolisher to dismantle, transport, recycle and/or dispose of them [4d].

6 Conclusion

6.1 IAI - Industry foundation classes

While the Lexis object-set overlaps the Industry Foundation Classes (IFC), they serve parallel and complementary purposes. Lexis addresses the aforementioned decision-makers ability to access, understand, and apply information from relevant reference libraries. It is concerned with the flow of information and is intended to support clear, concise communication between stakeholders regardless of the type and level of IT used. This said, there is no question that most of this communication will be computer based and therefore Lexis and the IFCs must be fully harmonised.

6.2 Developing an international language

Lexis in its current state of development is best described as a skeleton. The next step is to test and develop it in direct association with industry. While this work is proceeding in Australia, it is timely to consider the possibility of using Lexis as a starting point for the development of an internationally agreed upon language.

Reflecting on the experience of ISO/TC59/SC13/WG2 those involved, including this author, sought an internationally agreed *View*. In terms of the ideas presented above, the need is for international agreement on the objects in the *Core*. That is, to develop and maintain an internationally agreed data directory and set of exchange protocols with which individual countries, industry associations, and project decision-makers can construct and manage their respective *Views*.

Further, because the content is likely to be too volatile to be effectively managed as an ISO standard, it is recommended that national research organisations such as NRC, VTT, BRE, TNO, CSTB, and CSIRO come together to jointly undertake this work. The outcome would be an internationally harmonised public document written in the local language and marketed through the relevant building research authority. A Memorandum of Understanding between these organisations could ensure that the proceeds from the sale of these documents are applied to the language's ongoing development.

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212 A COLLABORATIVE ENVIRONMENT FOR BUILDING CONSTRUCTION PROJECT TOWARD COMPUTERIZATION OF TOTAL INFORMATION

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Abstract

This study aims at developing a collaborative environment for construction projects in order to computerize the project management of building construction. As a first simplification, the project management team is assumed to consist of the following staffs, manager, planning staff, technical staff, production staff, quality staff, material staff and financial staff, each representing a function for the project. It is proposed in this study that, a collaborative environment is provided and that each staff works on the environment to fulfill his own work, to share the project information with other staffs according to predefined rules for information access, and to coordinate with them. Domain models have been established, and a prototypical collaborative environment, which is used to manage the total project information in the proposed pattern and works on a client/server database management system on Local Area Network (LAN), has been developed.

Keywords: building, construction, information technology, project management

1 Introduction

In recent years, more and more computers have been used for construction management in China due to the improvement of their ratio of performance to cost. Softwares have been extensively used for such works as cost estimating, scheduling and accounting. Some projects have established LAN in the construction site office for sharing resources such as files and printers and some companies have even constructed intranet systems. The government is now accelerating the computerization of the national economy, which urges the effective use of computers

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in industries to raise the productivity. It is recognized that it is necessary to establish strategies for applying computers in view of integration in order to realize the computerization of the building industry (Ma and Chen 1998).

In the field of Computer Aided Engineering for Architecture/ Engineering/ Construction (AEC), many researchers are promoting the study on Computer Integrated Construction (CIC). In addition, the concept of Computer Continuous Acquisition and Lifecycle Support (CALS), which has been adopted by the military, are finding use in AEC. CIC and CALS are expected to contribute tremendously to the computerization of the building industry (Ma 1997). The proper modelling of the application domain is the key in order to take advantage of CIC and CALS. Many models have been established, and many prototypical systems have been developed as verifications of the models (Brown et al. 1998, Froese 1996, Stumpf et al. 1996, Rezqui et al. 1998). These works have provided many invaluable insights into the drive toward the implementation of CIC and CALS in AEC. However, many problems are still open for further study, one of them is how to apply the general models that have been proposed to specific domains in order to initiate the development of commercial applications.

Since a construction project is the basic cell of the building industry, it is proper to deal with it at first when promoting the computerization of the industry. This study focuses on the computerization of construction projects and proposes a new pattern of management of the total project information. Domain models have been established and a prototypical collaborative environment, which corresponds to the pattern and works on a client/server database management system on LAN, has been developed.

2 Patterns of management of total project information

As a first simplification, the project management team is assumed to consist of the following staffs, manager, planning staff, technical staff, production staff, quality staff, material staff and financial staff, each representing a function for the project. This simplification is basically in agreement with the project management organizations that are commonly in operation in China.

The total information management work that the staffs have to do, can be divided roughly into two stages, i.e. preparation stage and construction stage. In the preparation stage, the staffs are responsible for making the overall construction plans and schedules according to the design and the construction contract. In the construction stage, the staffs are responsible for making detailed plans, allocating relevant resources, organizing the production and guaranteeing the quality for every process of construction. The information that reflects the management work may flow among the staffs and is accumulated to form the construction documentation in different formats. Some of the documents must be submitted to the government administration as archives, to the owner for reference in the later stage of facility management, and to the representative of the owner and quality assurance agency as the proof of the construction quality, respectively. And other documents must be kept by the company for later use as reference.

2.1 Traditional pattern of information management

Traditionally, the staffs of the project team collects, stores and handles the project information using various forms while being in charge of certain processes of the construction project. Although computers have been used in some processes, for example in scheduling, the result (say, the schedule) needs to be prepared in paper form to be used by other staffs or by other organizations, such as the representative of the owner. In the construction documentation, some information is quoted in different forms, while others have to be transformed in several forms. As a result, not only the staffs have to do repeated works, but also it may cause redundancy and inconsistency in data and thus may invalidate some of these data. A collaborative environment provides an efficient solution to the problem.

2.2 New pattern of information management

2.2.1 Meaning of several terms

Before explaining the new pattern of information management, which we adopted in this study, two critical terms, i.e. collaborative working and environment, have to be clarified. In general, collaborative working means a situation, in which each staff fulfills his work and then the results can be obtained by other staffs immediately and the work can be continued. In this way, all staffs can share each other's information, and can cooperate intimately to carry out the work. On the other hand, by environment, we mean a common place where each staff may find the tools that he needs for his work, and at the same time, he can exchange data with other staffs conveniently. Such a collaborative environment usually involves a unified central data platform.

In addition, it is helpful to introduce the break down of a construction project. The construction stage of buildings consists of several phases, such as the phase of construction of main structures. Each phase consists of several processes, for example, the phase of construction of main structures consists of steel bar binding process, formwork installation process, the process of inspection on hidden work, and the process of in-site concrete casting etc. Further, each process consists of activities such as filling in certain data. Of course, since construction is carried out in space, the actual building is usually divided into many parts in each floor in construction, so that the above-mentioned processes and activities have to be iterated for each part in each floor.

2.2.2 Characteristics of the new pattern of information management

The new pattern of information management of construction project is based on the system configuration as shown in Fig. 1. According to this figure, a project team should construct a LAN in the construction site office. Then, the software of the collaborative environment should be installed in the server and in the client respectively. Here, the server is used to store the total management information of the project as a unified central data platform and to run the database management system, and the client is used to run the applications for the staffs. It is noted that the prevailing intranet technology is not adopted in this study. It is because the intranet platform is not practical in China now. However, it is only a problem of programming if we turn to the intranet platform.

Under the above system configuration, the characteristics of the new pattern of information management can be summarized as follows.

1. The total project management information is unified and stored in the central database in the server. A client/server database management system is used to manage the database so that the staffs can access the information concurrently. It also makes it easy to develop specific applications after the collaborative environment is put into operation and to reuse the data of the project afterward.
2. The staffs work on the collaborative environment to fulfill specific works such as retrieving particular information as well as routine works, such as recording relevant data or making data summaries. All kinds documents that must be submitted to the outside organizations can be generated from the central database by using the applications provided in the collaborative environment.

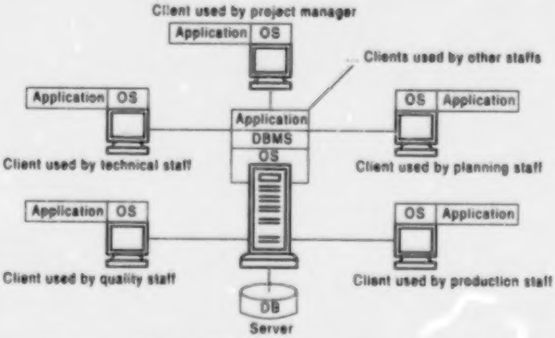
Client used by project manager
Application
OS
... Clients used by other staffs
Application
OS
Client used by technical staff
Application
DBMS
OS
OS
Application
Client used by planning staff
Application
OS
Client used by quality staff
OS
Application
Client used by production staff
DB
Server

Fig. 1: System configuration of the collaborative environment

3. Through the collaborative environment, all staffs share the total project management information according to predefined rules and communicate with each other in an easy way, thus the paperless environment in the project can be realized. For example, after the planning staff produces detailed plans on computer, he saves them in the central database. At the same time, the other staffs can access the plans on their computer and then carry out their work based on the plans. Similarly, the other staffs may return a feedback to the planning staff as well. At any time, the manager can check the work of his staffs through the collaborative environment conveniently. An e-mail system is also involved in the collaborative environment to facilitate the communication between specific staffs or between the manager and the staffs.
4. The workflow of the staffs is organized automatically by the collaborative environment. For example, once the formwork installation of concrete structures is finished, the collaborative environment notifies the technical staff and the quality staff to carry out the inspection on the hidden work. This

function is helpful for the new staffs and for reminding the staffs of their work.

3 Modelling of the collaborative environment

Establishing proper models is the prerequisite for constructing a robust collaborative environment. Three categories of models have to be established, i.e. the models for the project management information that are handled in the traditional pattern of information management, that for the information needed only by the collaborative environment, and that reflecting the workflow. Among them, the first two categories of models represent static information and are used to determine the unified central database structure, and the third category of model deal with dynamic behaviors and is used to organize the workflow.

In this study, we have establish the models for the construction phase of main structures of in-site-casting reinforced concrete buildings. The models for the other phases and for other kind of buildings could be established by following the same procedure.

3.1 Adopted methods of modelling

The object-oriented technology (Booch 1994) and the Pascot's Datarun method (Pascot 199€) were used comprehensively in the process of modelling in this study. Here, the former was used to identify the objects, their relationships and the relevant attributes, and the latter was used to extract the basic data from specific management processes and to determine the database structure.

By using the object-oriented technology in the highest level, two domain vocabularies were identified, i.e. the staffs and the objects involved in the construction process. These vocabularies were broken down further until the atomic entities are obtained. The hierarchy of the classes that were formulated based on the atomic entities was then established to distinguish the common attributes shared by a number of classes from the specific ones owned only by a certain class. For example, the attribute for any resource includes quantity, quality grade etc., while the attribute for any steel bar, a kind of resource, includes type, specification, location of production, ID number, site-entry-time, site-entry-quantity, and test result etc. as well as the attributes for any resource.

By using the Datarun method, major current construction processes were analyzed to build the business model, to identify the basic data based on the model, and then to construct the central database structure. The process that was analyzed in this study includes the management of planning, material, steel bar binding, formwork installation, and in-site concrete casting etc. The basic data that must be recorded by the staffs were identified in order to realize the idea that the staffs need input only the minimum information.

3.2 Major models for the collaborative environment

Based on the above-stated methods of modelling and by referring to the existing models for construction process (Froese 1996, Brown et al. 1998), we have established the models used for the collaborative environment in this study. The models are in different levels, where the high-level models are used as unifying references for the collaborative environment; while the low-level models are used for the actual database design and application design.

Four major models are shown in this section to illustrate the result of modelling.

3.2.1 Conceptual construction process model

As shown in Fig. 2, this is a high-level model reflecting the primary entities that are involved in the current construction process and the relationship among the entities. It is illustrated by using EXPRESS-G graphical notation (entities are represented as labeled boxes, specialization relationships are represented as heavy lines, and other association relationships are represented as labeled lines).

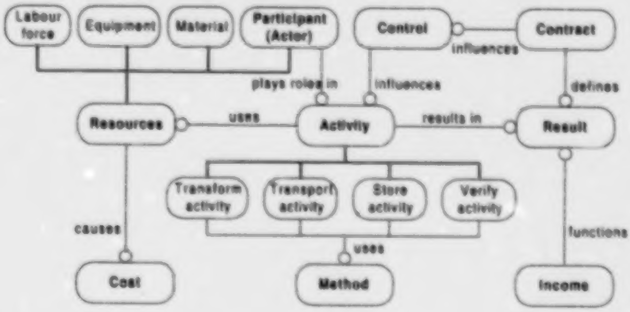

Fig. 2: Conceptual construction process model

3.2.2 Information management authority model

As stated before, in the collaborative environment, the staffs share the project information with other staffs according to predefined rules for information access. The information management authority model is used to specify the rules, as shown in Fig. 3. This model is adopted partly from a model in literature (Brown et al. 1998) and shows the entities involved in specifying the rules. In the model, the actor corresponds to each staff, the role to the function of each staff, and the authority to a set of rights that a staff possesses on an activity. For example, in the process of material test, a certain staff has the right of application for the material test, while another staff has the right to record the experimental results.

3.2.3 General system behavior model

The general system behavior model, being a high-level model as shown in Fig. 4, depicts the general behavior of all processes in project management of building construction and it can be used as a reference to establish the behavior model of each process. According to this model, processes are plan-driven. A plan for a certain process will be substantiated to the sub plans corresponding to each activity. When the process is finished, the feedback from the process is returned to the planning staff. Then the feedback can be reflected in the next plan.

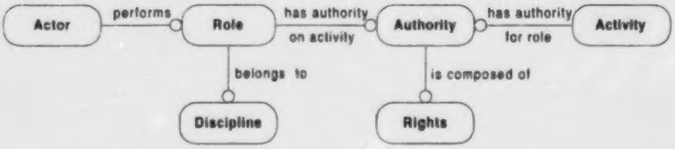

Fig. 3: Information management authority conceptual model

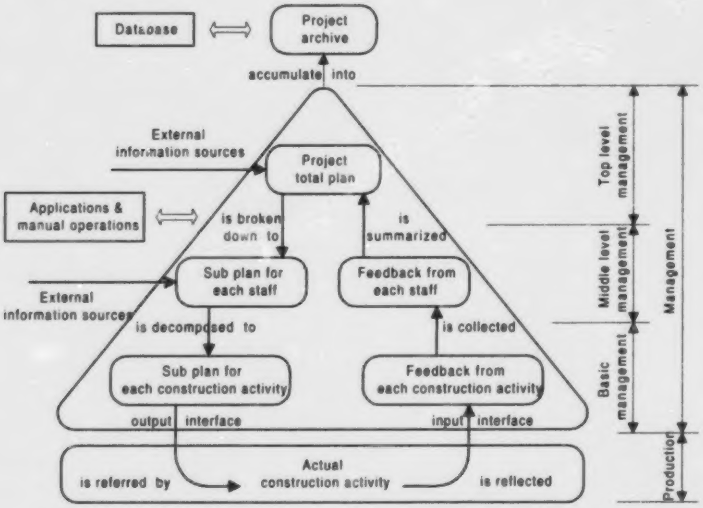

Fig. 4: General system behavior model

3.2.4 Example of system behavior models: for steel bar binding

Many models have been built corresponding to the system behaviors, here a model for steel bar binding will be illustrated. As shown in Fig. 5, when the process of steel bar binding starts, the collaborative environment should notify the technical staff to extract the steel bars from the design drawings for steel bar transforming, and to prepare the documents used for depicting the technical requirement. At the same time, the collaborative environment also notifies the material staff to make the plan of material provision. Further description for this figure is omitted because of limitation of space on paper. One may follow the figure to understand the whole workflow for this particular process. Obviously, this kind of model provides the rules for the collaborative environment to organize the workflow of the staffs for the project management of building construction.

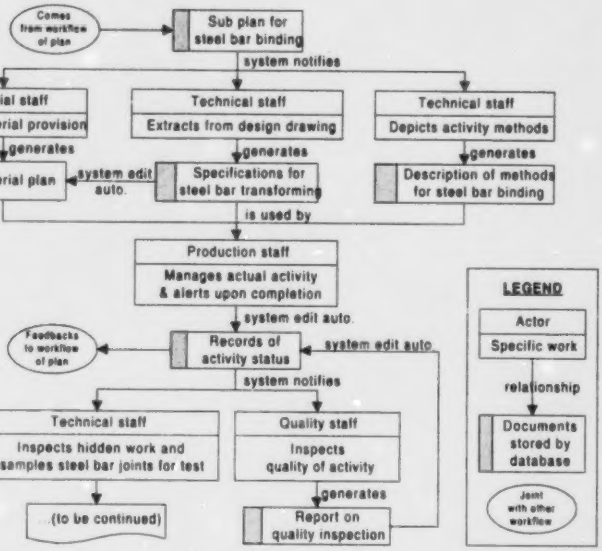
Comes from workflow of plan
Sub plan for steel bar binding
system notifies
Material staff
Plans material provision
generates
Material plan
system edit auto.
Technical staff
Extracts from design drawing
generates
Specifications for steel bar transforming
Technical staff
Depicts activity methods
generates
Description of methods for steel bar binding
is used by
Production staff
Manages actual activity & alerts upon completion
system edit auto.
Feedbacks to workflow of plan
Records of activity status
system edit auto
system notifies
Technical staff
Inspects hidden work and samples steel bar joints for test
...(to be continued)
Quality staff
Inspects quality of activity
generates
Report on quality inspection
LEGEND
Actor
Specific work
relationship
Documents stored by database
Joint with other workflow

Fig. 5: Workflow of steel bar binding

4 Functions of the collaborative environment

The functions that the collaborative environment should provide can be clarified based on three views. First, in view of an individual staff, the collaborative environment should provide a series of functions for each staff to fulfill his works. Some of the functions are in common, for example, the function of browsing the project information. While others are different, because different staffs are required to record different information and make different decisions.

Second, in view of collaboration of staffs, the function of communication, as well as the automatic organization of workflow, should be provided, so that not only can the staffs work according to the notification from the collaborative environment, but also they can take their initiative to work actively. Besides, the collaborative environment should provide the function of showing the results of collaboration. That is, if more than one staff is taking part in a certain activity, each staff should be able not only to see the progress of his work, but also to see the progress of work of other staffs who are taking part in the same activity.

Third, in view of making full use of the computer's ability, utility functions should be provided to help the user work more efficiently. For example, once the number of floor and the number of parts in each floor are entered, the collaborative environment should generate the activities of construction process automatically. The staff is allowed to edit the item of the activities and he does not have to input the items from scratch. In addition, various construction codes and specifications should be provided in the collaborative environment for users to look up efficiently.

The functions, which were determined based on the above considerations, are shown in Table 1.

Table 1: Functions of the collaborative environment

Menu item	Sub menu items	Menu item	Sub menu items
System	Project information Authority of information access Current information of processes Historical information of processes General information of project Codes and specifications E-mail	Confirm	Confirming of work state Confirming of work preparedness
		Technical	Construction diary Technical depiction Test application Evaluation of test result Technical support Technical inspection
Planning	Breaking down of process Construction planning	Quality	Quality inspection Quality analysis Handling of quality accidents
Material	Warehouse entry and exit registration Warehouse information Summary of material usage Analysis of material usage Material planning Material provision information	Test	Material test Construction test
		Archive	Project completion documentation Output of summaries

5 Implementation of the prototypical collaborative environment

The prototypical collaborative environment runs on a LAN. It consists of two parts, the server-side application and the client-side application. The former runs on MS SQL Server 6.5 on MS Windows NT Server 4.0 operating system, and the latter runs on MS Windows NT Workstation 4.0 or Windows 95/98 operating system.

The prototypical collaborative environment was developed using MS Visual C++ 5.0, and the central database was accessed by using ODBC 2.0. Most of the functions in Table 1 have been implemented, among them, many of the functions have been implemented ourselves, while some functions have been provided by integrating existing softwares. For example, MS Project 95 has been integrated in the collaborative environment for carrying out construction planning, and MS Excel 97 has been integrated to generate the summaries of project information. It deserves a mention that the existence of a central database system makes it easy to integrate other applications as well as to add new functions by using ODBC.

6 Conclusions

This paper focuses on the computerization of project management of building construction and has proposed a new pattern of total project information management based on the usage of LAN and a collaborative environment system.

Domain models have been established, and a prototypical collaborative environment, which is used to manage the total project information with the proposed pattern and works on a client/server database management system on LAN, has been developed. This work indicates that the pattern is feasible, and it seems that the methods used in the research are applicable to the computerization of similar fields.

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213 INFORMATION STRUCTURE FOR INTEGRATION OF FACILITY PROJECTS AT OPERATIONAL AIRPORTS

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Abstract

Airport Organizations are faced with the increasingly complex task of integrating facility development projects with operational airport systems. Computer network systems present promising opportunities for meeting this challenge. The goal of improving the integration of airport systems is similar to the goal of computer-integrated construction in the Architectural, Engineering, Construction and Facilities Management (AEC/FM) industry. In the AEC/FM industry, researchers are applying object-oriented, graphical models as a basis for data exchange. In this research, an information structure for the relationship of facility projects with airport management and operations is formulated using graphical modeling. The purpose of this model is for application as an airport facilities and construction management, information reference and retrieval tool. A prototype implementation based on this work is located on the Internet at: http://www.host.trueserver.com/needham.

Keywords: airports, construction, facility management, information retrieval, information structure, graphical modeling, systems integration

1 Introduction

Airport Organizations that own, operate, develop and manage large commercial airports are responsible for integrating a complex set of inter-related systems and resources. Effective-and-efficient utilization-and-coordination of these systems and resources continues to gain importance given increasing levels of commercial aviation, the high cost of infrastructure improvements, and barriers to the expansion of airport facilities. Opportunities for improving the effective and efficient implementation of airport functions exist in the use of information management technologies. These opportunities are particularly evident in computer network

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systems and associated communications, whose use in business applications is growing rapidly.

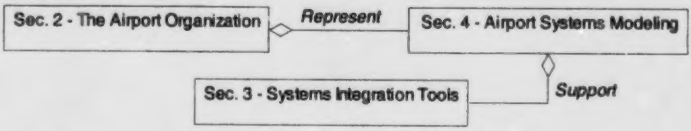
Sec. 2 - The Airport Organization
Represent
Sec. 4 - Airport Systems Modeling
Sec. 3 - Systems Integration Tools
Support

Fig. 1: Graphic model outlining the organization of this paper

The application of information management methods to classify and structure information required for the integration of facility projects at operational airport is the topic of a dissertation research project at The George Washington University, School of Engineering & Applied Science, Department of Engineering Management. Goals and objectives of this research are as follows:

a. Develop an information-structure representation for airport facilities and systems to improve information accessibility and integration of systems;
b. Identify and demonstrate a mechanism for detailing subject information;
c. Identify and demonstrate a mechanism for identifying subject relationships;
d. Provide a mechanism to assist in the identification of pertinent information;
e. Demonstrate an information management application prototype based on this research work; and
f. Identify methods that can be used within the developed information structure to improve organizational efficiency and effectiveness.

The organization of this paper parallels the methodology followed in the research effort: in Section 2, the airport organization's domain is described; in Section 3, systems integration tools are discussed; and in Section 4, the development of a systems model for airport organizations is presented. At the conclusion of the paper, pertinent findings of the research are summarized, and the status and location of the Internet-based, prototype implementation is given. Figure 1 outlines the organization of the body of the paper. The graphical models illustrated in this paper were developed using Rational ROSE-Student Edition, which is an object oriented software-engineering product of the Rational Software Corporation.

2 The airport organization

2.1 Business environment

Airport Organizations are one of three central business components that make up the operational portion of the United States commercial aviation industry. The other two are the commercial airlines and the Federal Aviation Administration (FAA). The ownership of airport organizations differ from the airlines and the FAA in that airports are traditionally owned by state and local agencies, whereas airlines are corporate entities and the FAA is part of the United States government. Numerous additional organizations and businesses are associated with or operate in support of commercial aviation. In North America *aviation activity has grown steadily*. From 1982 to 1992, growth was approximately 4.5 percent-per-year for passengers and 6.8 percent-per-year for cargo. (Kapur 1995) Forecasts are for aviation activity to continue to grow, with rates estimated at 4.0 percent-per-year for domestic U.S. travel and 5.3 percent-per-year for international travel for the period from 1996 to 2007. (FAA 1996) Increased congestion at many airports has resulted from these increasing levels of activity. In response, *numerous airport development programs* are planned and being implemented across the U.S. in order to improve facilities and increase capacity. These programs, save a few exceptions, have been restricted by various physical, social, political and financial constraints to the expansion and improvement of existing airports. (Rutner et al. 1997; Inamete 1993) The implementation of facility projects at operational airports is complicated by the need to integrate the development with ongoing operations and existing systems. The airport organization as owner, operator, developer and manager of an airport facility holds the primary responsibility for implementation of airport projects.

2.2 Principle functions and locations

The *three principle functions* of an airport organization are: provision of traffic handling systems; provision of commercial services; and provision of operational services. (Ashford and Wright 1992; Kapur 1995; Wiley 1986) Airport functions can also be generally *classified based on their location* as follows: on the public or landside of the terminal; in the terminal and aviation service facilities; or on the airfield operating area (AOA). *This research* focuses primarily on the interface of facility development projects with the airport functions located on the landside of the terminal facilities. Airport landside traffic handling systems include roadways and traffic control, way-finding information, pedestrian routes, on-airport transportation, terminal curbside facilities, and employee parking. Landside commercial activities include parking, curbside services, taxi-service, car rentals, and off-airport transportation. Landside operational services include site management, maintenance, utility services, police, fire and rescue. The implementation of facility development projects will typically affect many of these airport functions.

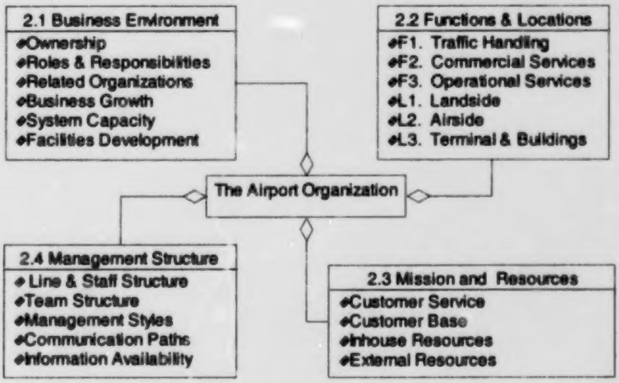

Fig. 2: Graphic model outlining the organization of Section 2

2.3 Organizational mission and resources

Provision of safe, efficient and responsive *customer service* is representative of a typical airport organization's mission. The *customer base* can be classified as consisting of passengers, senders, greeters, visitors and employees. A complicated mesh of in-house resources and contracted resources must be coordinated to meet customer demand. *In-house resources* are typically used for tenant management, management of business concessions, plant operations, facility project operations, maintenance operations, and for police and fire protection. Internal support is provided in the areas of human resources, finance, business services, engineering, public affairs, legal counsel, telecommunications and information systems. An *extensive array of resources external to the airport organization* is also required. Examples of external resources include: airline and cargo handling tenants; parking management and rental car business concessionaires; janitorial and landscaping service contractors; equipment vendors and material suppliers; and a variety of utility companies, engineering consultants, and construction contractors. Additional external resources include: federal agencies, such as the FAA and Postal Service; local public services, such as, public transportation, and water and sewer services; and a variety of interest groups and trade associations

2.4 Airport organizational management and communications

Formal communications and control within an organization are defined by the organizational structure and management style. The *line and staff structure* is commonly used by airport organizations. (Wiley 1986) This structure emphasizes vertical organizational relationships and is geared for stable business environments. (Moody and Premeaux 1993) The direct communications and rapid decision-making capabilities characteristic of line authority are combined with specialized staff that advise and assist the line function. There is a high degree of management flexibility and specialization, but internal conflicts between managers are likely. Effective communications and good working relationships can help minimize conflicts. The vertical structure is indicative of an autocratic or 'consultive' management style. (Miles 1975) These *styles* focus on work methods, and are characterized by formal communications that follow the chain of command in the form of directions passed down and feedback passed up. Information sharing between departments is permissible, although formal lateral communications at the lower levels of the organization are absent. Two-way communications can be utilized by management to help gain employee support for organizational objectives. In contrast, *organizational team structures*, such as the project and matrix structures, emphasize both vertical and horizontal organizational relationships. Team structures are geared towards more turbulent business environments. (Moody and Premeaux 1993) The inclusion of the horizontal structure is indicative of a human resource management style. (Miles 1975) This management style focuses on objectives, and is characterized by full availability of information, direct communication with lateral groups, and short feedback loops. Program and construction management consultants hired by airport organizations are likely to utilize a team structure. (Hendrickson and Au 1989) Within a large organization a variety of sub-structures and management styles are likely to be utilized and to change with time, which complicates the management process and the delineation of communications.

3 Systems integration tools

3.1 Systems integration

An Airport Automation Survey of computer systems was conducted by the Airports Association Council International, North America (AACI-NA) in 1992. Thirty-one U.S airports and two international airports were included in the survey. Results for three-of-the-five survey categories are summarized in Table 1. The two categories not shown here are financial management and hardware systems. It can be seen from the table that airport organizations use computer systems for a wide variety of applications. And although the trend for computer systems in general has been toward greater connectivity and interoperability, much work remains. The on going convergence of computing and communications, particularly in the area of network systems, however presents promising opportunities for increasing organizational effectiveness and productivity (Alter 1996; Laudon & Laudon 1996). The goal of improving the integration of airport systems through the use of information technologies is similar to the Architecture, Engineering, Construction and Facilities Management (AEC/FM) industry goal of computer-integrated construction. And in fact, there is a significant overlap of the airport industry and the AEC/FM industry, especially in the area of airport facility projects. Review of research directions and methods utilized within the AEC/FM industry shows compatibility and applicability to airport facilities work and to the overall airport organization.

Table 1: Airports with automated systems-33 surveyed (AACI-NA 1992)

Office Automation		Facilities Management		Operations Management	
Word Processing	33	Activity Statistics	24	ID Badges/Security	30
Spreadsheet	32	CAD/Engineering	23	Access Control	28
Database	28	Fire Alarm	21	Flight/Bag Information	21
Desktop Publishing	21	Building Energy Mgt.	20	Human Resources	15
Statistical Analysis	19	Lease/Property Mgt.	18	Incident Tracking	12
Electronic Mail	16	Maintenance Mgt.	16	Police Interface	10
Group Scheduling	16	Vehicle Maintenance	13	Airfield Lighting	9
Records Management	9	Construction Mgt.	11	Noise Complaints	9
Disaster Recovery	7	Fuel/UST Sensing	10	Baggage Handling	7
Document Mgt./		Travelers AM Radio	10	Police/Fire Dispatch	7
Imaging	6	GIS	8	Gate Scheduling	4
Executive Information	3	Central Plant	7	Vehicle Tracking	4
		Custodial Control	5	Taxicab Control	3

3.2 Systems integration research in the AEC/FM industry

The AEC/FM industry is characterized as a fragmented industry consisting of a large number of specialized firms and organizations. Vertical fragmentation exists between project phases, while horizontal fragmentation exists between the specialists within a phase. (Howard et al. 1989) In an effort to reduce this fragmentation, extensive research into the development of computer integrated systems has occurred. Examples of this research include overall strategies for computer integration (Teicholz and Fischer 1994). While work in specific areas includes the integration of cost and schedule data (Abudayyeh and Rasdorf 1991), the integration of design information with construction planning (Parfitt et al. 1993), and integration of construction product and process information (Stumpf et al. 1996). Larger-scaled, integration research and development projects include: RATAS (Bjork 1994); COMBINE (COMBINE 1998); COMMIT (COMMIT 1998); STEP (ISO STEP 1998); and the International Alliance for Interoperability's - Industry Foundation Classes (IAI IFC's 1998). A central theme in these integration research studies is the need for common conceptual models upon which to base data exchange. Modeling related research includes the primitive-composite approach (Howard et al. 1992), construction process information models (Froese 1996), and construction methods modeling (Froese and Rankin 1998).

3.3 Graphical modeling

The purpose of conceptual modeling is to develop a logical view of a system's structure. In database design, conceptual modeling is an important part of the information level design process, which precedes the physical level design process. (Pratt and Adamski 1994) While both lexical and graphical conceptual modeling techniques are available, graphical modeling was chosen for use in this work based on the strength of the visible representations produced. (Schenck and Wilson 1994) Graphical models are able to capture organizational structure, detailed subject information and subject relationships, which are three of the goals of this work. The two principle modeling techniques, which are similar in nature, are the entity-relationship model and the object-oriented model. The entity-relationship technique is formally defined and is used by designers of relational databases. The object-oriented model has not yet achieved a comparable level of conformance in practice, but has gained popularity based on its strength for matching data objects to real world components and processes. (Ryan and Smith 1995; Reingruber and Gregory 1994) Primarily for this reason, the object-oriented Unified Modeling Language (UML), a part of Rational ROSE, was chosen for use. In addition, student edition software and ample documentation is available, and it is likely that UML will become an industry standard. (Rational Software 1998)

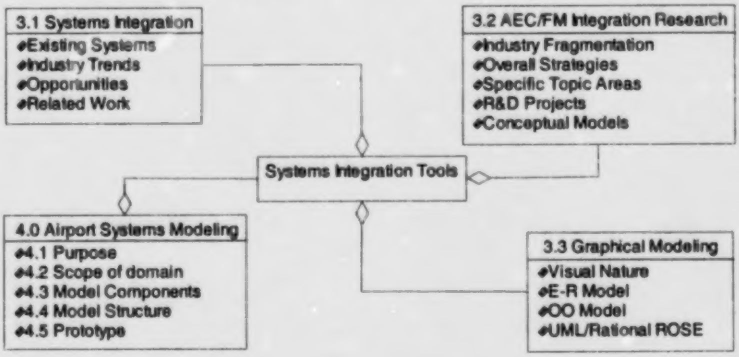

Fig. 3: Graphical model outlining the organization of Sections 3 and 4

4 Airport systems modeling

4.1 Model purpose

The *purpose* in preparing a graphical model of an airport organization's domain is for use in the development of an information reference and retrieval tool. The *underlying premise* is that representation and network computer implementation of subject and subject inter-relationship information used in facilities and construction management can be used to improve the quality of project implementation by reducing variations in operational, administrative, contractual and technical processes and products. The *objective* is to improve the organization's ability to identify and access pertinent information. The *aim* of the information model is for inclusion in the airport organization's Intranet system.

4.2 Model scope - the domain

Facility projects and project management at operational airports are subsets of the overall facility and organizational management structure, respectively. Therefore modeling of the overall information system structure is necessary to attain the full potential for improved systems integration. In other words, facility operations personnel, project development personnel, and management can reduce variations in work, and thereby improve organizational efficiency and effectiveness by improving the information set which they share. Accordingly, Figure 4 is a graphical representation of 'Level 1' of the information system model. The primary subject area being developed within the model is the interface of airport landside projects with operational airport facilities. A pedestrian tunnel project is being used to depict specific instances with which to validate and further refine the model.

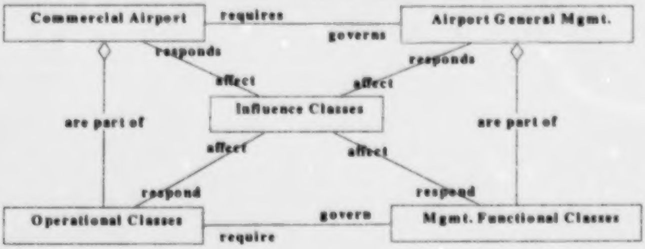

Fig. 4: Airport systems model - Level 1

4.3 Model scope - the model components

The components included in the modeling of airport systems include object classes, relationships, attributes and sample class instances. Types of relationships used in the model are associations, aggregations, and generalizations. Several 'use case diagrams' are also included as part of the systems modeling effort to illustrate specific organizational process interactions, along with the participating 'actors'. Modeling components not included in this research project include sequence diagrams, class operations and object behavior.

4.4 Model Structure

The model structure is partitioned in a hierarchy of model groups as follows:

Level 1- Model of the overall airport system;
Level 2- Models of the top level systems represented in Level 1;
Level 3- Models of the major classes represented in Level 2;
Level 4- Models of the object classes represented in Level 3; and
Level 5- Instantiation of model classes (Pedestrian Tunnel Project Example).

Object classes, objects, object instances, attributes, and object relationship are depicted graphically by the model. As an example, the 'Project Management Functional Class- Level 2' model is shown in Figure 5.

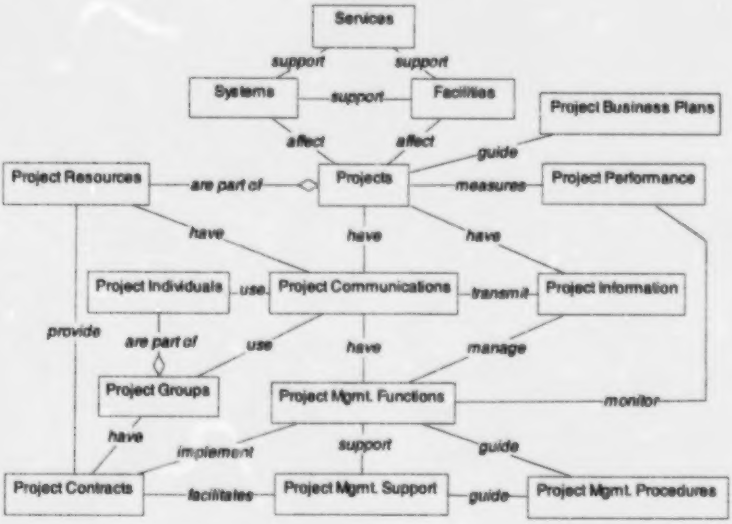

Fig. 5: Project management functional class model - level 2

4.5 Prototype Implementation

A web-based prototype is being implemented which uses the model structure as the 'site map' for navigating and locating information. The site was developed using Microsoft FrontPage 98 and is located at: http://www.host.trueserver.com/needham. The size of the model partitions and corresponding web pages have been controlled so that each 'model page' can be viewed with relative convenience using a web browser. The web pages were developed by 'pasting" the model partitions and adding hyperlinks. The prototype illustrates the use of a web browser as a means for activating graphical models, however it is limited in that the model is only partially developed and a database for instantiation of the model has not yet been developed.

5 Discussion

The goal of this research is to develop an information reference and retrieval tool that can be used by Airport Organizations to improve the project information management process. The research has focused on two aspects: first, the development of a conceptual information structure; and second a prototype implementation of the information structure. The background for the information structure was gained through research and experience with airport development projects. The top-down approach was taken in developing the model structure, however it is not expected or necessary that the entire model be detailed. Rather, the portion of the model of interest is that related to project operations and management, and the associated relationships with general management and other functional management areas. Three keys to validating the model are: ensure the scope of model is complete; check that object categories are appropriate and correctly detailed; and check that relationships are accurate and complete. A long-term, on going airport 'Pedestrian Tunnel' project is being used to help detail and validate the model. This amounts to a bottom-up approach for checking and detailing the model. The next step for validation of the model is for a sample group of the airport project personnel to review and critique the web-based prototype. The prototype is to have two primary features: first, the graphical components of the information structure are used for site navigation; and second a test-database for instantiation of objects. The navigational feature of the site is operational and demonstrates the general organization of the information structure developed. However, before operational testing by the sample group can begin the addition of a test-database is planned. The research methodology being followed does appear to hold promise given current opportunities with the development of organizational Intranet and Internet sites, and further development and testing is on going. Comments regarding the web site are welcome and can be made using the Email form available at the site: http://www.host.trueservercom/needham.

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214 FIRST EXPERIENCES WITH AN INCEPTION SUPPORT MODELLER FOR THE BUILDING AND CONSTRUCTION INDUSTRY

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Abstract

Inception and very early design of complex building and construction projects requires a large number of decisions to be made, considered, rejected, changed, or confirmed. Many views on the project co-exist at the same time, requiring complex communications and access to complicated knowledge covering the complete project and product life cycles.

Balancing the results of this non-monotonic decision taking process is (1) not a trivial task and (2) very important for the project outcome, as most of the product and construction process characteristics (like performance and cost) will largely be fixed. Further optimizations in later design stages will only be marginally possible.

In order to support the inception and very early design of complex construction project we are developing an Inception Support Modeler (ISM) that guides the user through the decision taking process. Decision taking is supported by a combined PDT (Product Data Technology) and KT (Knowledge Technology) approach.

The focus of the current modeler is on the inception of technical buildings, like Power or Process Plant Buildings, Factory Buildings, Hospitals and such. The product model and the knowledge base are developed in co-operation with the Brite-Euram CONCUR project.

The paper reports about the first test case of the ISM. As part of a demonstration in CONCUR, the ISM has been filled with Business Objects and Business Logic concerning the inception of a simple Turbine Building.

Keywords: PDT, CONCUR, Inception, Early design, Knowledge representation, Prototype

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1 Introduction

Despite a general agreement about the importance of the first few project stages (various sources estimate that between 70% to 90% of the total cost of the project costs are determined during the first project stages), inception and very early design of building and civil engineering projects is not yet adequately supported by Information, Communication and Knowledge Technology (de Ridder 1994;Mohsini and Davidson 1995; Vanier et al. 1996; Ozsariyildiz and Tolman. 1998).

In the inception and very early design stages of a construction project, the design and engineering team usually develops a number of alternative technical solutions for the facility that might satisfy the Client's needs. These alternative technical solutions are:

- Generally of a global, hierarchical nature,
- Often expressed as variants of existing constructions, for instance: a hospital like the Medical Centre in Amsterdam, but now for say 800 patients, or
- Combining a global hierarchy with variants for parts of the building (a façade like the one used for the Shell building in Rotterdam, but now with a different colour and only 12 stories high).

An alternative technical solution, which is required for a business model, eventually consists of a set of existing construction cases and construction products that, put together, provide the spaces for the required functions including: total volume, total floor area, performance requirements, logistical requirements, construction processes etc.

In order to support Inception of complex building projects by ICT and KT we need to define the Business Objects. These Business Objects are the foundations of the general architecture of an information system for inception support. The objects can be used to define a product database structure, but also to define the Business Rules and company workflow, which can provide more concurrent business processes.

2 The theory

Design and construction of building and construction facilities is, from a modelling point of view, very complex. If the business models are chaotic and unstructured, it is impossible to adequately formalise and reuse business objects and rules. Therefore our theory searches an answer to the question "How we can structure the complexity for reuse?" and integrates it with Knowledge Technology. The theory, as been discussed in more detail in earlier papers (Ozsariyildiz. and Tolman 1998; Tolman. and Ozsariyildiz 1998), is based on ideas presented in the General AEC Reference Model (GARM) (Geilingh 1998).

In the GARM, a product (facility) can be represented as a hierarchy of so-called Product Definition Units (PDUs) that covers the required Business Objects. Figure 1 gives a definition of the PDU in Express-G. A PDU can be a whole product, an activity or resource, but also a sub-system, element, component, part, or feature. For our purpose, we extend the scope of the PDU to also include typical project related information about the activities and resources required. PDU now stands for Project Definition Unit (Luiten 1994). The information of a PDU is given as a collection of characteristics. An Aspect determines each characteristics of a PDU. Examples of Aspects are cost, risk, quality, safety, sustainability and life cycle etc. Definition of a PDU in Express-G (Luiten 1994). A Project Definition Unit has Fig. 1:

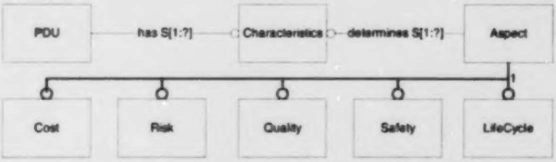

Fig. 1: Characteristics that are determined by one or more aspects (cost, sustainability, etc)

The GARM reference model makes a distinction between Business Objects that describe functions and solutions, i.e. Functional Units (FUs) and Technical Solutions (TSs). Each FU can be realised by one or more TSs that can be chosen from a set of alternative Technical Solutions. FUs on the same decomposition level can form one or many 'Interfaces', which in the original model could be modelled with a concept of Ports and End. Selecting a TS from a set of alternative TSs is covered by complex logic which in many occasions involves decisions about choices of TSs for other FUs. For example, the choice between the alternative TSs: Steel Structure, and Prefab Concrete Structure for the FU Structural Frame, will probably influence the choice between the TSs: Pile Foundation, Slab Foundation, or Raft Foundation, for the FU Foundation. Figure 2 illustrates the idea.

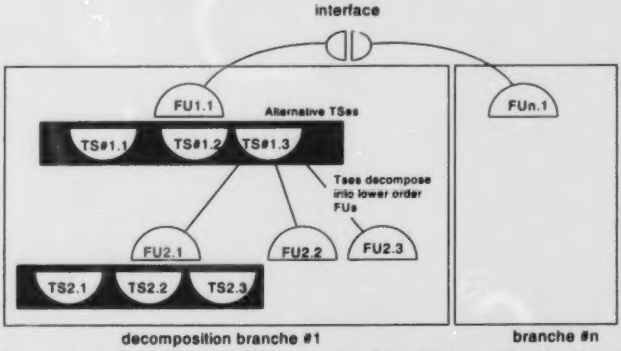

Fig. 2: Impression of an Interface between two FUs (Fu1.1 and FUn.1) in a generic hamburger model

Table 1: Part of the latest draft of the CONCUR ontology (Technical Building 'Turbine')

Level 0	Level 1	Level 2	Level 3
* New Built Power Plant Project ▪ Fuel ▪ Gas ▪ Thermal ▪ Nuclear			
	* Facility ▪ Turbine	* Zone	* Volume
		* Substructure ▪ Basement ▪ Bed ▪ Suspended	* Pile ▪ Sheet ▪ Replacement ▪ Displacement
			* Foundation ▪ Slab On Grade ▪ Pad ▪ Strip ▪ Raft
		* Superstructure ▪ Shell ▪ Tube ▪ Rigid Frame ▪ Conventional	* Frame ▪ Wall Slab ▪ Column Slab ▪ Column Beam ▪ Portal ▪ Space ▪ Column Cable
			* Roof ▪ Flat ▪ Hipped ▪ Gable ▪ Mansard ▪ Gambrel ▪ Jerkin-head ▪ Space Frame ▪ Folded Plate
			* Facade ▪ Masonry ▪ Cladding ▪ Panel
			Stairway ▪ Masonry ▪ Curved ▪ Spiral ▪ Winding ▪ One-Flight
		* Equipment ▪ Stream Turbine ▪ Gas Turbine	* Boiler
			* Condenser
			* Gas Turbine Unit
			* Generator
			* Stream Turbine Unit

▪ *Technical Solutions* * *Functional Units*

FU1.1 can be realized by each of the three alternative TSs (TS1.1 to TS1.3). As an example FU1.3 is decomposed into lower order FUs, each again with a set of alternative TSs

The Figure 2 also shows Interfaces between FUs on the same decomposition level (FU1.1 and FUn.1). This is done to create the flexibility to change complete sub-trees of higher order Technical Solutions, which is required for a non-monotonic decision and design process.

2.1 Business objects

TU Delft participates in the European Brite-Euram CONCUR Project (CONCUR 1999). Our prior focus in CONCUR is to define inception related Business Objects. The Business Objects covers a higher abstraction level of information that is relevant for the inception support. Those objects, cover not only the product process and project information, but also the business-related issues such as the contract types, the organizational break downs etc.

The CONCUR Project aims to deploy an integrated Inception to Tendering process supported by vendor available tools and models. The main goals of the CONCUR project are,

- to (help to) increase the competitiveness of the European construction industries,
- to develop and employ an electronic format for tendering,
- to shorten time and cost of tendering, while at the same time increasing the tender quality

Inception support plays an important role in the project. The main views on inception and early design are cost and time. In the CONCUR project, we therefore developed a FU-TS decomposition that specifically served the purpose of the inception process. Basically, the idea is that all the relevant cost related objects are included in a Hamburger model, and that a knowledge tool supports the selection and dimensioning of the TSs.

Table 1 below, shows a part of the latest draft of the CONCUR ontology, as a hierarchy of FUs. Level 0 and level 1 covers ballpark or square-meter cost calculations and level 2 and 3 covers the elements that are relevant for conceptual and bill-of-quantities cost calculations.

2.2 Business Logic

A typical characteristic of inception decisions is, that there are not much crisp values and algorithmic procedures available. Most of the relevant knowledge is expressed (1) both in rules-of-thumbs and comparison of old cases in fuzzy sets (like a range of cost figures 120$ - 140$) or (2) in fuzzy terms, for instance cheap, or expensive, high-rise, or low-rise buildings etc. and like ballpark square-meter cost calculations, which are formulated from cases (earlier projects). Often the knowledge is not precise, therefore allowance for vagueness and uncertainty should be made especially while assessing risk factors for all abstraction levels of Business Objects. Above all, construction projects are one of a kind projects, which means that we always will have to adapt earlier solutions to new circumstances. So flexibility and adaptability of the knowledge base are primary design considerations.

A typical expert system normally uses a fixed set of rules. In practice the fact list changes continuously, new facts are defined and old ones being removed at all time. However, the percentage of facts that changes per unit of time is generally fairly small. For this reason, we decided not to use the classical expert system technology, and to use a very efficient method known as the Rete (Greek for "net") algorithm (Forgy 1982). The classic paper on the Rete algorithm ("*Rete: A Fast Algorithm for the Many Pattern/ Many Object Pattern Match Problem*")[1] became the basis for a whole generation of fast knowledge base engines such as: OPS5, its descendant ART, and CLIPS (1999). Therefore, in order to be flexible to modify and edit the knowledge base we choose CLIPS as our knowledge engine. The Business Rules and Logic are stored in the project knowledge base. The Business Logic is open so that domain expert can modify the company specific knowledge. At the knowledge level Interfaces store Business Logic and Rules and at the information level it stores dependencies, associations and relations of Business Objects.

2.3 Case study turbine-housing

For 100 Mw power plants or smaller ones, there are two main types of Turbine-Housing available. The first one has only one floor; the second one has two floors, with or without extension (in height). In the Turbine-Housing equipment can be grouped as Back-Pressure turbine (gas), or Condensing-Power turbine (steam). The Gas Turbine requires usually one floor housing and the Steam Turbine requires two floor housing. Sometimes extra height is needed when there is additional equipment in the housing or when the site is narrow. Both housing types may have an intermediate level of steelwork. Housing can be constructed in-situ or prefabricated. Some parts of the building can be reinforced concrete.

Aspects taken into account in this case study are constructability, stability and stiffness.

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[1] *Charles L. Forgy, Artificial Intelligence 19(1982), 17-37*

3 The ISM prototype

The current design and implementation of the Inception Support Modeller (ISM) applies state of the art Product Data Technology (PDT) and KT. The ISM consists of four modules, as shown in Figure 3. The first module, where the GARM (General AEC Reference Model) is being used as a reference model, supports the formulation and capturing of knowledge about the Business Objects. The second module helps the end user, to define the relations and rules between different functions with respect to Business Rules, Business Logic. In addition, this module helps to choose the required alternative Technical Solutions; in other words, helps to create project early specifications for client requirements. The third module is used for verification of the user requirements. The system has a connection to a project database where project inputs are gathered. In addition to that, the system gives advise while choosing alternative TSs to support what-if scenarios. Finally, the forth module visualises the occurrences of the TSs by using a CAD-system or a VRML browser. The end user can change the parameters of various shape descriptions, including those parameters that are covered by other aspects such as economics, lifecycle, durability etc, which are relevant for inception and early design.

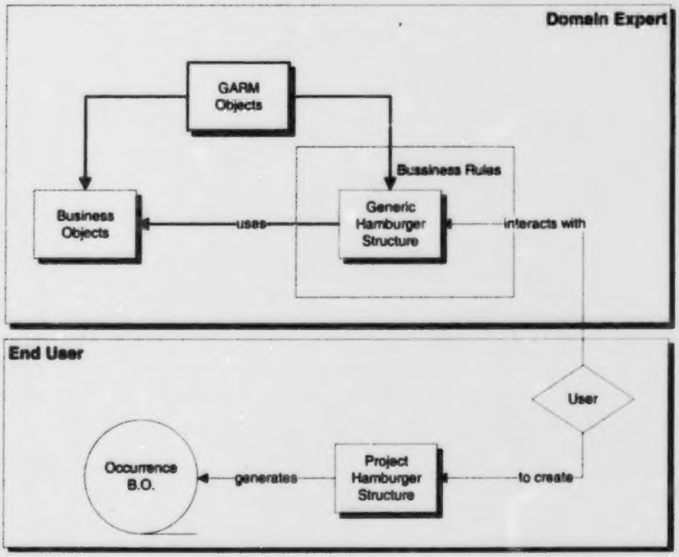

Fig. 3: The GARM Objects are used for generating business objects and business rules

The knowledge is stored in a generic Hamburger Structures in the knowledge base. The end user creates a project specific Hamburger Structure by interacting with the KB. The KB generates the database structure for occurrences of Business Objects.

3.1 The user interface

The prototype ISM uses a simple Windows based point and click user interface that allows the user to quickly enter his data and evaluate the results. The system will at any time allow the user to choose alternative TSs and parameter values anywhere in the project Hamburger tree, so that a non-monotonic decision process can be supported. Figure 4 below shows the current user interface.

The dashed rectangle shows the FUs, TSs, Aspects and Value Domains. The selected FU (Power Plant Project) is automatically linked to a set of aspects that are listed and it is fulfilled by a range of Technical Solutions such as coal, oil, gas and nuclear. Aspects are linked to Value Domains to define the Characteristics of Technical Solutions. The system will update the knowledge base synchronously.

The FU-TS decomposition provides us not only with a structure suitable to capture project knowledge but also supports formalization and re-use of earlier projects as cases. For instance, the FU Pile Group has TSs such as Prefab, In-situ, or Wooden. However, a user can simply express knowledge about a previous project such as: PileGroupInProjectXYZ. By adding the characteristics of this Pile Group the system will update the case base where all past experiences are stored. The user does not need any prior knowledge more than their product knowledge. The system itself is capable of converting product knowledge to matching-rules or meta-rules.

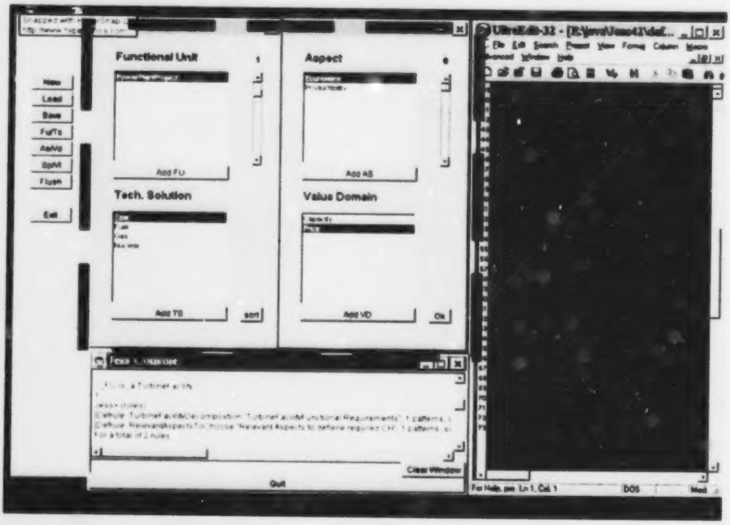

Fig. 4: Picture of the user interface of the inception support modeller (ISM)

The example is the same as in figure 2. By pointing, clicking and adding parameter values, the user provides the information from which the system generates the rules (shown on the right) that are input for the knowledge engine.

3.2 Project KB

The Business Objects, which are structured according to the GARM reference model, are dynamically reflected in the project Knowledge Base. The Functional Units, alternative Technical Solutions and required Characteristics of the Technical Solutions are transferred to the KB as project or product related rules. For instance the Functional Unit "TurbineFacility" can be fulfilled by Technical Solutions Gas, Coal, Fuel and nuclear.

```
defrule TurbineFacilityAlternativeSolutions
        "TurbineFacilityAlternativeSolutions"
          ( _FU ( name "TurbineFacility" ) )
          =>
          ( _create _TS name "Gas")
          ( _create _TS name "Coal")
          ( _create _TS name "Fuel")
          ( _create _TS name "Nuclear")
```

The end user simply chooses one of these solutions, or the system makes suggestions about the best suitable solutions based on the requirements. If the user chooses a TS the system gives the Characteristics of the solution in comparison to the requirements.

Related to all Business Objects every Technical Solution has Characteristics, a Value Domain and a certain Value define Characteristics. For example, if the country is "The Netherlands" then the Characteristic of the country Labour-Productibility-factor is "0.95" and VAT Tax-Rate is "17,5" etc. An other country will have different Characteristic pattern.

```
defrule TurbineFacilityCountry
          " TurbineFacilityCountry Information"
          ( _TS ( name "The Netherlands" ) )
          =>
          ( _create _VD name "Labour-Productibility")
        ( _set _ VD  name "Labour-Productibility"
         (_property value "0.95" ) )
          ( _create _VD name "Tax-Rate")
        ( _set _ VD  name "Tax-Rate"
         (_property value "17,5" ) )
```

```
defrule RelevantAspectsToChoose
          "Relevant Aspects to define required CH"
          (  relevant-aspects  $?aspectList )
          =>
          ( printout t "Relevant Aspect is_a" crlf )
          ( foreach ?aspect $?aspectList
                   ( printout t " - " ?aspect crlf )
                   ;;Define the aspects
                   ( _create _AS name ?aspect )
```

Every Characteristic of the Technical Solutions is defined by an Aspect in such a way that different views on the same product can co-exists. Based on different criteria the user can make his decisions. Aspects are used to define different views on the same product. For a certain type of project, economics can be a valid view and for another type visual aspects can be dominant view.

For complex problems it is important to support upstream and down stream knowledge transfer. Usually project alternatives have different Hamburger structures. In the prototype, decomposition rules can either be written as Functional Unit decomposition or FU-TS decomposition. For example Turbine Facility can have different TSs and if a user sees a risk in the turbine site he can

```
defrule TurbineFacilityFunctionalDecompostion
          "TurbineFacilityFunctional Requirements"
          ( _FU ( name "TurbineFacility" ) )
          =>
          (  _ask "What are the relevant Aspects ?" $? )
          ( assert (relevant-aspects $?) )
          ( _create _FU name "TurbineBuilding")
          ( _create _FU name "TurbineEquipment")
          ( _create _FU name "TurbineSite")
          ( _create _FU name "TurbineService")
          ( _set _FU name "TurbineBuilding"
        (_property level "1" ) )
```

decompose the facility and verify the what-if scenarios.

3.3 The end user

Visualization can be done with Virtual Reality Modeling Language (VRML) for the Internet based support of the early client project specification. The connection is done via IFC file exchange. Figure 5 shows as an example a 3D view of a simplified Steam turbine generator plant which is developed by FORTUM engineering which is collaborating in the CONCUR project. The CAD system is automated with D++[1] software in order to support drafting. The D++ interface supports interaction with the end user. When the decision taking process is complete than the system sends the required information to the central database, or generates IFC 1.51 file as an output IFC files are converted to VRML format. The Client can see and click on the defined item's to get more information about the design. In the future the connection with ISM tool will be online and realized by an http-based client server connection.

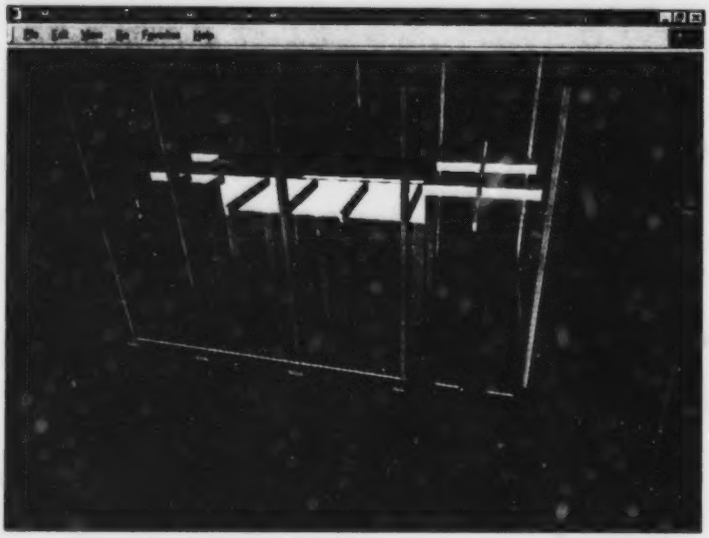

Fig. 5: A Simplified VRML visualization of the steam turbine generator plant generated by FORTUM engineering

At the moment the tool ISM described above has been filled with the generic Hamburger model that is derived from Table I, and the relevant Characteristics and parameter values are being added. Application of the system for simple Turbine Buildings gives encouraging results. However for application on real life cases still more emphases is needed on Business Logic and Rules.

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[1] *Design Power Europe Oy*

4 Conclusions

The Inception Support Modeler (ISM), which is being developed by TU-Delft in co-operation with the Brite-Euram CONCUR project, supports the selection and instantiation process that takes place during the inception and very early design stages. See it as an intelligent checklist, which has knowledge about the things one can chose or cannot chose.

The knowledge gathered in the system as a case study, focuses on the power plant marketing and early building related design, not on power plant equipment. However the system has an open architecture so that knowledge about equipment and its interaction with the building can be easily incorporated. Elaborating the Business Objects and Business Logic will continue for a couple of years. It is our aim that the ISM can be applied to many other project types for instance hospitals, warehouses, factories etc.

Although our experience with the ISM tool is still limited and improvements and extensions are needed, we believe that the basic knowledge structure adopted for inception and very early design is right. Knowledge acquisition can be performed in a structured way and the resulting partitioning of the Knowledge Base is quite understandable and easily extendable. Another good point is the extendibility for the search mechanisms, such as existing cost databases and building component libraries, which seems to work fine.

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215 CONSTRUCTION INFORMATION ACCESS THROUGH A "MALLEABLE FRAME"

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Abstract

Information management is critical to the success of a construction project. Because of the fragmentation of construction information and the volatility of construction projects, information sharing and collaboration are important measures to achieve successful project information management. However, many current research projects focus only on shared project information. A gap between the shared project information and the non-shared project information still exists. This paper shows models and methodology to bridge the gap and make a document "malleable" according to user's needs by using contemporary computer technologies such as XML (eXtended Markup Language) and WDDX (Web Distributed Data eXchange). Some details about specifications for implementation are also presented.

Keywords: Shared project information, non-shared project information, document model, specification, hypermedia, XML, WDDX

1 Introduction

As the Internet based technology such as the WWW (World Wide Web), e-mail, e-commerce, e-bid and e-builder, becomes ubiquitous, many practitioners in the construction industry believe that "the Internet and its relatively simple working environment is the catalyst that will change the construction industry from paper to digital communication – particularly in the way of project collaboration and project management (ENR 1998)." Nevertheless, there is still a long way to go to achieve such a goal.

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1.1 Problem description

Construction industry is notorious for information fragmentation (O'Brien 1993). From the object-oriented point of view, information, or attributes, related to an object is better to be placed together logically or be coherently and consistently connected through some mechanisms in order to facilitate information management (Martin and Odell 1998). However, since information related to the same object might be generated at different project stages by different people using different software tools in the construction industry, it is quite common that the information is physically, technically and semantically isolated. For example, a "slab-on-grade" object has information about its estimating, its scheduling, its budget, and its drawing. Because of the information fragmentation, the mapping of the relationships among those types of information requires manual translations. One solution to this problem is using a shared database, while the estimating, the scheduling, the budget and the drawings are different views to the same database (Fischer and Froese 1996). This solution works well for the shared project information, such as project drawings and manuals. However, for private information such as budget and cost accounts, even if the private information is modeled by using the same semantic model as that of the shared project information, there is still a need for bridging the private information and the shared information. This means because of the business constraints, the information fragmentation still exists even if the shared database approach is used.

Construction industry uses a lot of documents as communication media. One of the direct reflections of the above problems is that the information in the documents prepared at remote sites (by other project participants) may not be directly and automatically reused to retrieve related information by the local project information system. For example, a contractor may receive a Request for Change Order Proposal (RCOP) referring to a work item, "slab-on-grade", while the local system may have some associated information about that work item such as scheduling, budget, and estimating. The contractor normally need to know these types of information to prepare a return document, a Change Order Proposal (COP). However, when an architect is preparing the RCOP, he/she does not know what kind of information the contractor may need and where the information is. Therefore what the architect can do is to prepare a conventional type of document that only expresses what the document is and what kind of return information is expected. This approach is quite reasonably although not user friendly or user oriented.

Because of the existence such a problem, it relies on the document viewer to interpret the document and find the associated information. Very often what is in the document may not be what the user wants. Unfortunately the conventional document itself cannot do anything to help this situation. It will be a great step forward if there is a system that can not only present the document but also serve as a gateway to other related information. Such a system will definitely improve project participants' job efficiency.

This project is to use contemporary computer technology to build a prototype of such a system for the construction project participants, which is named **Kaleidoscope**.

1.2 Overview of Kaleidoscope

The purpose of **Kaleidoscope** is to provide project participants a system that allow them to automatically retrieve relevant information from local sources without resorting to other systems and also allow them to tailor the display according their own needs. **Kaleidoscope** is for Web-based applications and portable for different database systems and platforms.

Currently, there are three types of Web-based applications in construction industry. They are "fee-based project management service", "build it yourself solutions", and "Web-enabling software" (ENR 1998). The "fee-based project management service" such as Blue-Line/On-Line (1999) and Emerging Solutions (1999) provides a central server for project Web sites, allowing project participants to log on at different security levels to upload and download project information. Such systems are implemented as Web databases, providing users with organized data entry and retrieval mechanisms with different views. The "build it yourself solutions" such as the Aspects ProjectServer and Site-Builder by Black & Veatch (1999) focuses on similar technical approaches only without information outsourcing. The "Web-enabling software" such as the Primavera Project Planner (1999) can generate Web ready reports based on its own data sources. Nevertheless, those systems do not have a mechanism to deal with the problem mentioned previously. **Kaleidoscope**, as a complement to those systems, is designed to give project participants a more integrated working environment that provides them with the capability of dealing with information from different sources simultaneously.

1.3 Implementation technology

The implementation of **Kaleidoscope** relies on a mixed use of hypermedia design, XML (eXtended Markup Language), WDDX (Web Distributed Data eXchange), and Java.

Hypermedia design methods such as HDM (Hypermedia Design Method)(Garzotto et al. 1993), OOHDM (Object Oriented Hypermedia Design Method)[10] and RMM (Relationship Management Method)[11] are the major tools for designing specifications for dynamic hypermedia generation.

XML is a new Web technology. As a subset of SGML (Standard Generalized Markup Language), XML gives software engineers and developers a tool to automate the processing of Web documents (Bosak; St.Laurent; Microsoft Corp.; Sall; DOMS; XML; Walsh; Paoli and Workshop 1999). For **Kaleidoscope**, XML provides a fundamental meta-language for structuring construction documents and provides a tool for manipulating the documents as well.

WDDX is a new technology for integrating databases with different computing environments such as Java and JavaScript (Forta and Allaire 1999). The technology is based on XML by using XML syntax to form a system independent data format. In **Kaleidoscope**, WDDX is great helpful because **Kaleidoscope** relies on a neutral data format to transfer data between local databases and the **Kaleidoscope** environment, which is Java in this case.

The implementation of **Kaleidoscope** is done by Java program language.

2 System design

2.1 System architecture

Figure 1 shows the system architecture of **Kaleidoscope.**

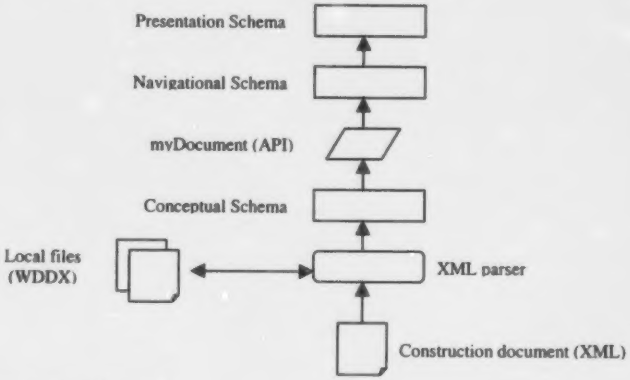

Fig.1: System architecture

The system starts with a construction document that is prepared in the XML format. The construction document is then parsed by a XML parser. In this project, the IBM parser is used. During the parsing process, some units may need to get local information. This is done by sending out a universal key and other information to local systems in the WDDX format. The results from local systems, if any, are stored in WDDX format as well and sent back to the parser. The results after parse are several trees, namely a tree structure representing the construction document and some tree structures representing local information. The local information is always related to some different document units. Therefore, logically there is only one tree. The tree forms the conceptual schema. To access to and manipulate the tree, myDocument, APIs (Application Programming Interfaces), is provided. Although we can always use W3C DOM (World Wide Web Consortium Document Object Model) APIs, myDocument provides a simplified set of APIs that are designed for applications involving local information. The navigational schema defines access structures. **Kaleidoscope** provides three kinds of access structures, which are the document index, the local information type index and the local information mixed index. The implementation of these access structures and the related presentations rely on the services of myDocument. The presentation schema organizes presentations according to tasks and provides interface features for user interactions.

2.2 Conceptual schema design

The application domain of **Kaleidoscope** is relatively simple yet dynamic. It is simple because only a few entities may actually be involved. Those entities only include a construction document and related local information. Therefore it is not like many other hypermedia applications that may have tens or hundreds of entities. However, it is more dynamic because for different types of construction documents, the information types in the document as well as related local information types may change. This means the hyperbase of **Kaleidoscope** is ever changing according to different construction documents. For most of other hypermedia projects, they always have very clear and stable hyperbase in terms of entities and their attribute types. To solve the problem, **Kaleidoscope** uses a more generic conceptual schema.

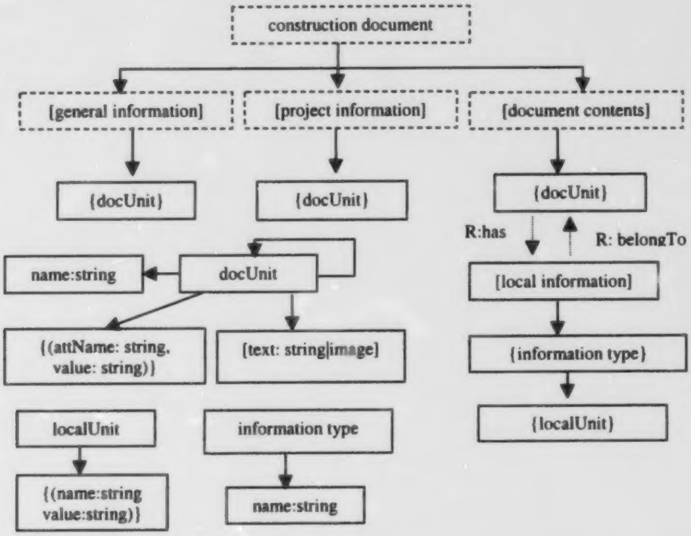

Fig. 2: A "conceptual schema" for Kaleidoscope

Following the principles and the concepts of HDM, **Kaleidoscope** structures construction documents into three levels, namely entities, components and units. The documents themselves represent entities. Each document contains three types of components, general information, project information and document contents. General information includes units such as document titles, document dates, document id, document senders, document receivers, document checklists and signatures. Project information includes project names, project ids and project participants. Document contents include names of work items, descriptions and attachments. Units of the components are equally referred to as "docUnits".

Similarly, information retrieved from local databases is structured in the same way. On the top, local nodes stand for entities, below which local information types, such as scheduling and estimating stand for components and their attributes are the units. The units here are referred to as "localUnits" to be distinct from the "docUnits".

In order to cover different construction documents and different local information, the conceptual schema is designed as shown in Figure 2 and Figure 3 respectively.

The notations used in Figure 2 and later are only to serve the purpose of this project. Explanations of the notations are as following:

- The boxes in dash lines contains structure information only, and do not have any document information. The boxes in solid lines represent both the structure and the contents of a document.
- "[ ]" means that the elements inside it may appear zero or once only; "{ }" means that the elements inside it may be generated zero or more times. "( )" means that the elements inside it appear in pair; Elements that have no braces or brackets around them, such as the "name:string" of "information type", must appear exactly once.
- "R" stands for special relationship, represented by dash arrowhead lines. Therefore here we have two special relationships. A "docUnit" may "has" a "localUnit" and thus the "localUnit" "belongTo" the "docUnit". Other relationships, such as the structural relationship, the perspective relationship and the application relationship are equally represented by solid arrowhead lines.
- "Text" and "image" stand for the type of the elements. " | " means "or". And ":" is for type explanation.

Local information is stored in a neutral data format shown as Figure 3.

```
<localNode>
<id>id</id>
<uid>uid</uid>
{<localInformatioType {name="value"}>}
</localNode>
```

Fig. 3: Data format for local information

Figure 3 shows that one local node, which corresponds to "local information" in Figure 2, may have zero or more types of local information. Each type of local information may have zero or more pairs of name and value, which correspond to the name and value pairs of the "localUnit" in Figure 2.

In this way, local information that is related to one "docuUnit" may be grouped together under one node. For example, the "slab-on-grade" mentioned earlier may have local information of scheduling and budget. Under the same node, "localNode", scheduling and budget are two local information types. Within each type, such as scheduling, name and value pairs, such as "early start = 1/12/98", are included.

2.3 Navigational schema design

The navigational design defines three access structures for users to manipulate the information defined in the conceptual schema. These structures are a document index, a local information type index and a local information mixed index. These indexes are defined in Figure 4.

In the navigational schema shown in Figure 4, there are several new notations used. They are:

- "<!-- … -- >" stands for comments.
- "docUnit.Name" means the name of this "docUnit". "." is used for representing this relationship.
- "confirm" stands for a confirm bit that captures user's interactions. The "confirm" is not a part of document information, therefore it is not shown in the conceptual schema. However, logically each "docUnit' and each "localUnit" have a confirm bit.

Document index:

```
<!-- general information -- >
{(docUnit.Name: string, confirm: boolean)}
<!-- project information -- >
{(docUnit.Name: string, confirm: boolean)}
<!-- document contents -- >
{(docUnit.Name: string|image, confirm: boolean)}
```

Local information type index:

```
<!-- document contents -- >
{docUnit.Name: string}
<!-- local information -- >
{Information type: string
   {(localUnit.name:string,
    confirm: boolean)}
}
```

Mixed local information index:

```
<!-- document contents -- >
{docUnit.name: string}
<!-- local information -- >
{Information type: string
  {(localUnit.name: string,
    confirm:boolean)}
}
```

Fig. 4: Navigational schema of Kaleidoscope

The local information type index and the local information mixed index are always associated with a certain document unit. They cannot exist alone.

The index structures control the traverse across the hyperbase developed in the conceptual schema. They also provide access points. The actual display is determined according to user's interactions and the "confirm" bits will indicate to the system what to display.

Corresponding to each of the above indexes, there are three types of display templates. The specifications of these templates are shown in Figure 5.

In the template for document display, the only action is to display the "text" of a "docUnit" if the "confirm" of the "docUnit" is true. The condition is wrapped inside a

"{ }", which means that there may be more than one "docUnit" selected. Thus the "display()" is wrapped inside a "{ }" as well to be congruous with the condition.

The templates for the local information type display and the local information mixed display are similar. Both of them have a "isTrue(docUnit.R:has)" condition. This condition is to check if a "docUnit" has a local node. If a "localUnit.confirm" is "true", the "name" and "value" of this "localUnit" are displayed. In order to make the display clear, the "information type" of this "localUnit" and the "name" and the "text", if any, of the "docuUnit" that the "localUnit" indirectly belongs to are displayed as well.

The differences between the two local information index templates are that the mixed local information display allows simultaneously display of different information types, thus it needs to check zero or more "confirm" bits. The other template however only needs to check zero or once. Consequently, the display of the mixed local information is wrapped inside a "{ }", while the display of the other template does not.

Construction Document Display:

```
Condition: {docUnit.confirm = =true}
Action: {display(docUnit.text)}
```

Local Information Type Index Display:

```
Condition: isTrue(docUnit.R:has) = =true
           [localUnit.confirm = =true]

<!-- document unit -- >
Action: display(docUnit.name,
                docUnit.text)
<! -- related local information -- >
Action: display(information type)
        display(localUnit.name,
                localUnit.value)
```

Mixed Local Information Index Display:

```
Condition:
isTrue(docUnit.R:has) = = true
{localUnit.confirm = = true}

<!-- document unit -- >
Action:
display(docUnit.name, docUnit.text)
<! -- related local information -- >
Action:
{display(information type)
    {display(localUnit.name
              localUnit.value)}
}
```

Fig. 5: Specifications for various display templates

2.4 Presentation schema design

The presentation schema design includes presentation design, user interface design and process design. The purpose of the presentation schema is to organize presentations for different states of different tasks.

2.4.1 Presentation design

The three display templates discussed in the previously section are abstract designs, they do not say how the information is presented to a user. Presentation design includes specifications for such purposes. Again, the document layouts are subject to document types. Thus, here we only consider some generic feature, while leaving the actual document layouts to different applications.

The rules for presentation are based on matching. For instance, the document index shown in Figure 4 determines what is to display by set the "confirm" to "true" and the display templates shown in Figure 5 tells what to do under certain conditions. Now the presentation template shown as Figure 6 determines how the information is perceived by users. The presentation templates inherit conditions and display functions from the display templates in Figure 5. They have additional conditions however showing the rule for generating presentations. The rule is matching. This is done by the condition, "This.name = = docUnit.name" or "This.name = = localUnit.name". Here, "This" refers to the unit selected by the user in the index template. Once "This" unit is selected, the name of "This" unit is send back for searching a unit with the same name in the document tree and the local information three. If the name is found, and the corresponding content, "text" or "name", exits, the corresponding display is carried out and presentation is configured by "set ( )" .

The presentation templates are generic templates for various kinds of units.

Document Unit Presentation:	**Local Unit Presentation:**
Condition: inherit conditions from the display template; This.name= =docUnit.name; isExist(docUnit.text)= =true; Action: inherit display from the display template set(font, fontColor, alignment,..)	Condition: inherit conditions from the display template; This.name= =localUnit.name; isExist(localUnit.name)= =true; Action: inherit display from the display template set(font, fontColor, alignment,..)

Fig. 6: Unit presentation specification

2.4.2 User interface design

Although the focus of this project is not on interface features, the interface design is an unavoidable part. Thus here we only work on the bottom line to show that the designed mechanism works. Following we will discuss main user interface features of **Kaleidoscope**.

Major screen layouts include a toolbar for different menus and a main presentation window. The menus include "Document" to set views for documents, "Local Information" to set views on one type of local information, "Mixed Local Information" to set views on multi-types of local information and "Process" to switch states. Obvious, "Document" is the implementation of the document index, and "Local Information" is the implementation for the local information type index and "Mixed Local Information is the implementation for the local information mixed index. Buttons will be used as triggers for those menus. The contents of these menus are generated dynamically according to different documents.

Once a document is opened, the document index is always active to users to set default views or tailor a display. Since the local information type index and the local information mixed index are always related to a certain unit in the document, these indexes are not active until the user selects a proper unit. To help users identify what units have local information, the system will attach a checkbox to the right unit and also make that unit appear different from others. Therefore, if there are many units that have local information, **Kaleidoscope** can provide local access to one unit a time.

A construction document may include some attachments. They are shown in separate windows. Once a document is opened, the attachments are shown automatically by default unless the user reset it in the "Document" menu.

3 Conclusion

This paper presents models, specifications and methodology for developing a hypermedia system that will make a project document prepared by others malleable to the document viewer. This gives project participants some capability manipulate the document in the way they want. This also break the limit of conventional documents that the views of those documents are set and fixed by the party who prepares the document. The document in **Kaleidoscope** is thus more user friendly.

However, **Kaleidoscope** is based on two major assumptions that require further studies.

3.1 Assumption one

This project is to use XML to represent structured construction documents. Currently construction documents are not structured in a way that fits the requirements of XML. Most importantly, the vocabulary set of construction documents needs to be assumed. For instance, this project may use following XML tags denoting some nodes in a construction document, shown as Figure 7.

```
<documentType docName="changeRequest" id="CH-123">
Request for Change Order Proposal
</documentType>
```

Fig. 7: An example of a construction document in XML format

In the above example, the node name, "documentType" and the attribute name, "docName", are part of construction document vocabulary. This vocabulary has to be an industrial standard, or de facto standard. Currently, such vocabulary does not exist yet, let alone to say an industrial standard.

3.2 Assumption two

One of the major features of **Kaleidoscope** is its ability to combine a document with some related local information. This project however can only show a theoretic solution, because one key technical problem has not been solved in building construction. This technical problem is of a universal index (uid) system. Once a node is designed to search for local information, the node passes its uid to the local system so that the local system can do search and retrieve based on this uid. In the building construction, such an index does not exist currently. What we have now is a very rough uid, such as the CSI (Construction Specification Institute) indexes. Such indexes cannot meet the requirement of this project. Therefore in this project it has to be assumed that the work items in a construction document and their associated information in the local system can be uniquely identified.

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PART SIXTEEN

IT AND THE CONSTRUCTION PROCESS

216 UTILITY ASSESSMENT OF ELECTRONIC NETWORKING TECHNOLOGIES IN CONSTRUCTION

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Abstract

Despite an explosive growth in virtually all areas of industry and commerce, Electronic Networking Technology (ENT) has only begun to make inroads into the construction industry practice. Although information exchange protocols in construction firms and on construction project sites make it difficult to take advantage of most ready-made solutions applicable in other industries, there is a significant potential of large benefits from the correctly developed and applied ENT solutions for construction firms and construction project site offices. This paper describes the ongoing research effort to determine variables related to the application of ENT protocols for the main types of construction project delivery systems and to measure the utility of ENT configurations in facilitating communication between parties involved in a construction project with respect to specific project delivery systems.

Keywords: Electronic Networking Technologies, Internet, Intranet, Multiple Attribute Value Measurement, project delivery system, utility assessment

1 Introduction

The key to maintaining and upgrading U.S. built infrastructure is the technological prowess of the construction industry, a $500 billion plus business and the largest contributor to the national economy. Construction industry at the end of the 20th century is facing many challenges from the market, as the forces to change and to incorporate new advanced technologies into the construction process become stronger (Fisher and Yin 1992). Construction, like branches of other industry, has already entered the information age by using information technology in a variety of ways. Yet the information technology is still used in a disintegrated fashion and there

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are many limitations with the current use of information technology in construction (Betts et al. 1991).

Meanwhile, the construction industry suffers from fragmentation, since within any sizeable construction project the project organization is complex and has many phases. A project team consists of many parties with different level of knowledge, disciplines, expertise, resources and interests. The project life cycle is divided into several separate phases, (i.e. feasibility study, design, procurement, construction, operation and maintenance, and eventual retrofit or demolition.). This management environment in the construction industry is widely believed to be a significant impediment to successful implementation of information technology in construction. Problems of implementation of information technology in construction are in essence organization and technology integration problems, involving the exchange of information and knowledge among different parties to a project. Pudicombe (1997) suggested ways to achieve organizational integration by the use of contractual and social/psychological approaches, and to achieve technological integration by the use of integrated computer technology.

2 The need for communication tools

One approach that has been used to incorporate the organizational integration is related to the management system which the owners choose in conducting the project. This approach is based on facts that the degree to which the construction can be integrated into the process is determined by the project delivery system (Walker 1996). The traditional method, i.e. separate design and construction, fragmented the phases and the construction team. In recent years, the owners have started to implement other delivery systems that can increase the degree of integration, such as design-build, turnkey and Build-Operate-Transfer (BOT), as well as by allowing a constructor to participate in the design process and creating more designer/contractor teamwork (Gordon 1994).

That approach is supported also by the adoption of Concurrent Engineering into the construction industry from manufacturing industries. Concurrent Engineering is intended to improve the performance during the design process by considering all aspects of the project's downstream phases concurrently, eliminating of non-value adding activities, and encouraging multi-disciplinary team (Love and Gunasekaran 1997). To implement this, there is a need for tools that can support collaborative environment. The enabling information and communication technologies are important in the establishment of effective communications protocols for collaborative work in construction management (Anumba 1996).

For accommodating technological integration, the concept of Computer Integrated Construction (CIC) is commonly used. CIC is a computer-based concept that is intended to integrate project participants into a collaborative team with the utilization of computer applications through all phases of a project (Teicholz and Fischer 1994). From some experiences, the communication technology to transfer information plays important role in CIC implementation (Miyatake et al 1992).

Regardless of the approaches used in incorporating integration in construction, communication tools is a must. The greater the level of collaboration and concurrency in a process, the greater the level of coordination required. This will lead to more communication between phases, processes and parties.

3 Electronic networking technologies as communication tools

There are enabling information technologies that have a potential for use in all integration aspects in construction. One such technology is the Electronic Networking Technology (ENT), which includes the Internet, Intranet and Extranet technologies. The ENT has attracted the world's attention with its distinctively advanced features, such as platform, time and geographic independence. Since it emerged about 30 years ago, Internet has been evolving very fast. It is now becoming a collection of networks, with millions of individuals and businesses connected to the Internet, and it is growing faster as the World Wide Web (WWW) emerged. ENT is widely believed to be capable of supporting collaborative work environments. The Forrester Report concluded that Internet and Intranet technologies will remove many of the obstacles to collaboration within firms and across teams, and predicted that the more useful collaboration tools will appear by the end of 1999 (Brown et al. 1996).

In order to implement the approaches for enabling electronic integration in construction using ENT, careful planing and innovative strategies are needed. Gerstein (1987) concluded that the critical element is neither the application area nor its underlying technology that makes IT strategically important. It is the specific role of a particular technology application to a given industry at a point in time that makes the difference. Regardless of how attractive the use of ENT in the construction industry may seem, the efforts of implementing such technology should be preceded by the evaluation of its utility in a specific application scenario. The evaluation will determine whether the ENT based applications in construction project management will perform as intended.

4 Objectives of ENT assessment

The main objective of the assessment effort is to measure the utility of ENT for various types of construction projects, and further specific objectives are derived as follows:

1. To determine attributes to be considered in measuring the utility of ENT for a given construction project with a particular project scenario.
2. To measure the utility of ENT for construction industry, with regard to the degree of integration associated with the specific project scenario.
3. To develop optimal ENT configurations for various type of construction projects based on the assessed value of utility of ENT.

5 Utility of electronic networking eechnologies

Utility is only one of the measures of practical system acceptability under attribute of usefulness as depicted in Fig. 1. Here, utility is defined as the ability of the functionality of the system to fulfill in principle what is needed by the user.

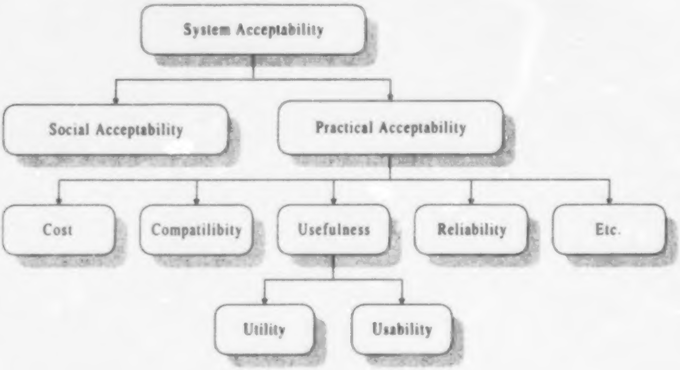

Fig. 1: Model of the attributes of system acceptability (partially adapted from Nielsen 1993)

Based on the above definition, the utility of a system can be measured with respect to its functions. A successful system in terms of its utility requires much attention to the characteristics and identity of the user, the user's task being supported, and the environment in which the system operates. Those aspects suggest the implementation of a human-machine system (Shackel 1991) as depicted in Fig. 2. With this framework, the definition of system utility can be broadened to include determination how the available system can support the user needs in performing a particular construction management task in a given environment.

Deploying the above framework into the electronic tools for project management will explain the definition of the utility of ENT for construction projects. Furthermore, the utility of ENT for construction projects can be defined as to how the ENT services can support project tasks during the project life cycle. The utility of ENT will vary depending on the project task, the project parties involved, and the environment in which the task is taking place. It means that the utility of ENT will vary depending on the type of project delivery system used in the project since for each project delivery system the project task, the characteristics of the parties involved and environment of each stage are different. The utility of ENT for each project delivery system is useful in determining the ENT configuration for a particular project scenario. Different configuration of ENT will be needed for different project scenario not only for facilitating different type of project tasks and users, but also for accommodating different level of collaboration and concurrency in each project delivery system.

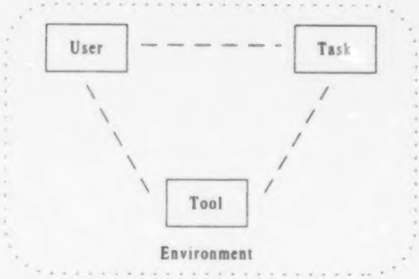

Fig. 2: Human-machine system (partially adapted from Shackel 1991)

6 The tool for measuring the utility of ENT

To evaluate ENT utility, measurement criteria based on ENT performance and users' attitude can be used. Evaluating the utility of a system such as ENT is not only a matter of evaluating the performance in supporting the user's tasks, but also evaluating the user's experience in performing a given task with the use of the given ENT system. The typical intended users of the suggested evaluation technique are construction management professionals that use ENT in some of their most challenging projects.

A feasible tool for use to measure the utility of ENT is the Multi Attribute Value Measurement (MAVM). MAVM is an appropriate tool for measuring user preferences. Direct Rating method can be used to assess the single attribute value of each attribute, Ratio Estimation can be used to assess the weights, and the additive function model will be used for aggregation model (Winterfeldt and Edwards 1986).

Measuring the utility of ENT for every type of project delivery system can be useful as a feedback for decision making process in a variety of decision tasks such as:

1. Whether to use ENT in a given construction project using a specific project delivery system; by comparing overall utility of ENT for all types of projects within this category.
2. To what extent a project will use ENT; by choosing a particular ENT which hold some criteria in term of utility.
3. How to increase the functionality of ENT to support construction processes; by analyzing ENT that have low utility with respect to a particular attribute.

7 Assessment methodology

In order to achieve the stated objectives, the assessment methodology is organized into three parts. The first part deals with the project delivery system, the second deals with ENT, and the third with assessing the utility of ENT for the given project type. The assessment scenario is depicted in Fig. 3.

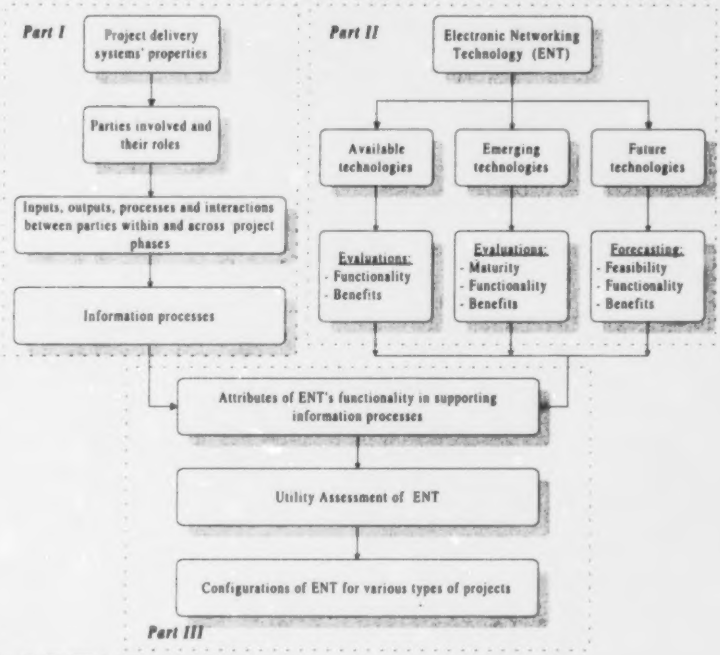
Part I
Project delivery systems' properties
Parties involved and their roles
Inputs, outputs, processes and interactions between parties within and across project phases
Information processes
Part II
Electronic Networking Technology (ENT)
Available technologies
Emerging technologies
Future technologies
Evaluations:
- Functionality
- Benefits
Evaluations:
- Maturity
- Functionality
- Benefits
Forecasting:
- Feasibility
- Functionality
- Benefits
Attributes of ENT's functionality in supporting information processes
Utility Assessment of ENT
Configurations of ENT for various types of projects
Part III

Fig. 3: ENT Assessment Scenario

The first part of the assessment scenario is intended to investigate characteristics and the role of the potential users of ENT in a construction project, the users' tasks that can be supported by the use of ENT, and the environment where the user's tasks are performed in every phase of the project life cycle. All possible processes that can be supported by ENT will be developed and analyzed by focusing on information processes.

The second part of the scenario is intended to investigate the type of functionality provided by ENT (i.e. Electronic mail, File Transfer Protocol, World Wide Web, Archie, Video conferencing, etc.), not only the ones that are already available but also the ones that are emerging and might be available in the future.

The third part develops the assessment system of the utility of ENT for various construction projects and for implementing ENT in specific application scenarios. Attributes to measure the utility of ENT can be developed by focusing on the information process supported by ENT. MAVM can be used further to measure single attribute utility and overall utility of ENT by assigning weights to each attribute.

The implementation of the assessment system can be accomplished by using expert reviews by industry practitioners. For this purpose, a questionnaire can be developed to enable the assessment of the utility of ENT. The questionnaire can be distributed to the respondents over the World Wide Web. The content of the questionnaire can be based on the developed assessment system and the selected procedure of MAVM. The results of the implementations of the assessment system can be useful to draw conclusions and to determine the configuration of ENT for various construction projects.

8 Implementation example

This implementation example describes a hypothetical utility assessment of ENT for a hypothetical project scenario. Some assumptions made for this example are:

1. The selected project delivery system for this example is a general contractor (GC).
2. The parties involved in this project are: owner, architect/engineer, contractor, suppliers and subcontractors.
3. All parties have been using ENT for supporting their operations and projects.
4. The objects of evaluation are the functionality of Internet and Extranet, such as electronic mail, FTP, telnet, list server, newsgroup etc., in supporting construction processes. Assume there are three functionalities to be evaluated, which are E-mail ($i = 1$), FTP ($i = 2$), and WWW ($i = 3$).
5. Attributes for measuring the objects of evaluation are the ability of ENT to distribute the information (D), to search the information (S), and to distribute the information (R). All attributes are assumed independent of each other.
6. The evaluation is focusing on five processes in the construction phase, which are: schedule monitoring ($j = 1$), submittals and document control ($j = 2$), change management ($j = 3$), process invoices ($j = 4$), and cost monitoring ($j = 5$).

The single attribute values of the objects of evaluation have values between 0 and 10, and are assessed using the Direct Rating method. The weights of the importance of attributes and processes have values between 0 and 1, and are assessed using the Ratio Estimation method. The aggregation of the single attribute values are performed using an additive model as follows:

$$V_{ij} = W_D \, . \, V_{ij}(D) + W_S \, . \, V_{ij}(S) + W_R \, . \, V_{ij}(R) \tag{1}$$

$$V_i = \sum W_j \, . \, V_{ij} \tag{2}$$

Where i is the number of ENT functionality to be evaluated and j is the number of construction processes. The single attribute value of $V_{ij}(D)$, $V_{ij}(S)$, and $V_{ij}(R)$ are the utility of i ENT functionality in distributing, searching and retrieving information respectively for construction process j. W_D, W_S, and W_R are the weights of attributes of the ability of ENT functionality in distributing, searching and retrieving information respectively. These weights are assessed by comparing the importance of the attributes to each other in a particular construction process. The utility of i ENT functionality for construction process j (V_{ij}) can be derived using equation **(1)**. The utility of i ENT functionality for a particular project delivery system (V_i) can be derived using equation **(2)**, where W_j is the weight of process j that can be assessed by comparing each construction process with respect to their importance in the project.

For this implementation example, the result of the assessments by the respondents of the questionnaire and the aggregation of single attribute values are depicted in Table 1 to 4. Table 1 depicts the assessed weights of processes and the weights of attributes *D*, *S* and *R* for each process.

Table 1: Assessed Weights

Construction Process (j)	Process Weight (W_j)	Weight of Attribute		
		W_D	W_S	W_R
1	0.2	0.40	0.40	0.20
2	0.2	0.50	0.14	0.36
3	0.2	0.38	0.38	0.25
4	0.2	0.40	0.20	0.40
5	0.2	0.40	0.40	0.20

The assessed single attribute value of each object evaluation for each process is depicted in Table 2 to 4 under column 'Attribute'. Using the assessed weights from Table 1 and the additive models (1) and (2), the aggregation of single attribute values are calculated and depicted under 'V_{ij}' column.

Table 2: Assessed single attribute value of utility of E-mail (i = 1)

Project Phase	Construction Process (j)	Attribute			V_{1j}
		Distribute	Search	Retrieve	
Construction	1	4	2	6	3.60
	2	9	8	8	8.50
	3	8	6	8	7.25
	4	7	8	8	7.60
	5	4	2	6	3.60
				V_1	6.11

Table 3: Assessed single attribute value of utility of FTP ($i = 2$)

Project Phase	Construction Process (j)	Attribute			V_{2j}
		Distribute	Search	Retrieve	
Construction	1	6	5	8	6.00
	2	7	5	6	6.36
	3	4	5	6	4.88
	4	2	2	3	2.40
	5	6	5	8	6.00
				V_2	5.13

Table 4: Assessed Single Attribute Value of Utility of WWW ($i = 3$)

Project Phase	Construction Process (j)	Attribute			V_{3j}
		Distribute	Search	Retrieve	
Construction	1	7	8	6	7.20
	2	5	8	5	5.43
	3	8	8	4	7.00
	4	5	3	3	3.80
	5	7	8	6	7.20
				V_3	6.13

Some conclusions can be drawn from Table 2 to 4 which are associated with the construction process $j = 1$, which is schedule monitoring:

- The ability to distribute and to search information of WWW are assessed to have the biggest value ($V_{31}(D) = 7$ and $V_{31}(S) = 8$). While FTP is assessed to have the biggest value in retrieving information ($V_{21}(R) = 8$).
- Using an assumption that the feasible functionality should have value of utility of ENT more than 5.0, FTP and WWW are assessed to be feasible for monitoring of project schedule ($V_{21} = 6.00$ and $V_{31} = 7.20$).

For other processes, the same approach can be used to have the acceptable utility of ENT functionality for particular process. Furthermore, using an assumption that the feasible functionality for supporting a construction project should have value of utility of ENT more than 5.0, all evaluated functionality in the example (i.e. E-mail, FTP and WWW) can be used for supporting a GC project delivery system since $V_1 = 6.11$, $V_2 = 5.13$ and $V_3 = 6.13$. Further analysis from the conclusions above will arrive at the configuration of ENT for a GC project delivery system.

9 Conclusion

ENT as enabling communication technologies in distributing, searching and retrieving information for construction processes are expected to solve the organizational and technological integration problems in construction. Implementation of ENT should be proceeded by the evaluation of utility of ENT which can be assessed by Multi Attribute Value Measurement technique. The result of the assessment can be used to develop the optimal configuration of ENT for a particular project delivery system and its processes.

This paper describes the ongoing research effort to determine variables related to the application of ENT protocols for the main types of construction project delivery systems and to measure the utility of ENT configurations with respect to specific project delivery systems.

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217 IMPROVING CONSTRUCTION COMMUNICATION: THE IMPACT OF ON-LINE TECHNOLOGY

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Abstract

The Special Projects Administration (SPA) of the Ministry of Public Work in the State of Kuwait is responsible for managing the construction of Kuwait's prestigious facilities that are, usually, complex and costly. This paper suggests a Web-Based Information Delivery Intranet Site as a complementary communication tool that would enhance the delivery and exchange of information on the SPA's construction projects. Also, the paper includes areas of improvements to the SPA's communication process as a result of incorporating the WWW technology in communication. Improvement on the information delivery time is found to be the most significant.

Keywords: Communication, multimedia, WWW, information technology, on-line.

1 Introduction

It is hard to ignore the importance of the emerging technologies in leading the construction industry to a competitive edge. One such technology is the on-line multimedia technology that can add value to the communication process among the construction project's participants. Effective communication is essential for the functioning of any organization. Breakdowns in communication contribute to a group of problems that result in low work productivity and quality.

The impact of the Internet on the construction industry is seen in the area of "Open Collaboration" that transcends time zones, national and organizational boundaries and even language [Brides 97]. The move toward more collaborative

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working within the construction industry is a welcome one given the numerous problems that have resulted from the industry's fragmentation and adversarial posture [Anumba and Evbuomwan 96]. The combination of HTML (Hyper Text Markup Language) based Web pages with Java Applets, CGI (Common Gateway Interface) Scripts, Databases, FTP (File Transfer Protocol), peripheral devices, and new data formats creates an endless universe of possibilities for collaborative engineering [Rojas 96].

The A/E/C firms in Kuwait need collaborative working environment through continually developing and improving its communication processes to achieve project objectives. Minor improvements in communication become, even, more important in managing large and complex construction projects. One of the major agencies in Kuwait that needs to continually improve its communication process is the Special Projects Administration (SPA) of the Public Works Ministry.

This research suggests a supporting tool to the current communication process used in the SPA. The supporting tool is an on-line Information Delivery and Exchange Site that would complement the oral and written communication channels of the (SPA) and constitute a basic Intranet environment. A general evaluation of the Web technology, through browsing web pages of different web sites around the world, one can extract the preliminary benefits that the Web Wide Web (WWW) technology can add to the SPA's communication process. It could reduce cost by reducing printed papers usage, phone and FAX charges, manpower doing secretarial work (calling, printing, mailing, etc.), postage costs, and information processing time. Also, the SPA, as an agent for public projects, can have access, and vice versa, to large international contractors and qualified bidders through WWW technology.

2 Background

The SPA manages large and prestige public construction projects; and therefore, little savings in time and/or cost, as a result of improved communication efficiency, can add up to be potential toward the end of the project. Examples of recent projects under this administration include the Amiri Diwan and the Kuwait University projects with total cost of KD 150 million and KD 220 million respectively.

The SPA's main communication processes consist of three types: face-to-face meeting, telephone, and written communications. Written communication is the most formal in the SPA because it provides hard copies for storage and retrieval in case documented evidence is needed in the future. SPA's written communication channels, mainly, include letters and memorandums. Letters in the SPA, are used through out the project life cycle to document action, convey information, give instructions, and monitor work progress; whereas memorandums, short written forms and less formal then letters, are often used for documentation of communication or as a record action (SPA Reference Manual 1997).

While lines of authority are well defined in the SPA which makes communication easier, the administration is moving slowly in exploring new means to improve the communication efficiency and result in better productivity. New and advanced means of communication channels include: electronic mail, video conference, computer software (e.g., integrated databases), voice mailing, and the on-line WWW technology. There are many barriers to accepting and implementing new technologies in the SPA, one of which is the assumption that such technologies have high price tap, including the cost of training, for its benefits. Proving, to the SPA's decision makers, that such barriers are no longer so and that a lot of benefits can be gained from utilizing advanced technologies in communication would be an important step in the way of developing a technology strategy for the Kuwaiti construction industry.

3 Objectives

This research implements and evaluates a new medium of communication as a means of improving the effectiveness of communication in the SPA. That new medium is a WWW based, and is best described as a Web-Site or a Web-Page. WWW is, basically, a scheme for using the electronic Internet to exchange information in hypermedia formats which is achieved through a web site or location that acts as its server.

This paper presents a Web-Based Information Delivery Site as a complementary communication tool that would enhance the delivery and exchange of information on the SPA's construction projects. Also, the paper includes areas of improvements to the SPA's communication process as a result of incorporating the WWW technology in communication. The www technology is a valid experimental area because it has not been tested before in the SPA, it is a current issue in Kuwait, and it holds a lot of promises.

4 Communication channels and facilities

The electronic communication that has been implemented includes all types of communication necessary between the SPA and other main parties during all project stages. In the pre-design stage, the main parties are the owner, end user, Ministry of Planning, Audit Bureau, and Kuwait Municipality. In the design stage, two more parties (design consultants and MPW administrators) join the communication channels. In the tendering stage, two additional parties (the Central Tendering Committee and general contractor) join the team. In the construction stage, the supervision consultant joins the team.

The communication between the SPA and other project parties is extensive especially with the design consultant and the contractor. Generally, the A/E maintains open communication channel with SPA at all times. The contractor, on the other hand, has numerous obligations towards the SPA including:

- Temporary & mobilization works
- Daily construction reports
- Submittals and transmittals
- Project schedule approval and updates
- Material/equipment permit
- Request for subcontractor approval
- Progress meetings
- Payment certificates
- Provisional sum release order
- Variation order
- Substantial completion form
- Final completion certificate

The SPA Web media includes all project documents, especially the plans and specifications of projects. Communication facilities in a given project include memos, letters, and reports. Project reports are the main formal means by which project progress is communicated and recorded. As records, they are vital parts of the projects audit trail, so they must be prepared with all possible care. Project reports should:

- State clearly the current status of the project
- Compare actual achievements with planned target achievements
- Draw attention to critical issues
- Identify problems and propose solutions
- Promote effective management and control

Project reports should preferably be based on 'exception' reporting, i.e., highlighting variations from the plan. This helps the reports to be concise and forward looking. Effective management and control needs timely action, so project reports must be produced regularly and promptly. It is usually better to have roughly accurate information quickly than to have precisely accurate information late. Consequently, posting project reports on the SPA-Web site is the fastest distribution method.

The main implementation reports are: a) progress reports, b) cost reports, c) earned value reports, and d) debrief reports [Kartam 99]. The latter type of reports provides the means of learning how to improve the management of future projects. By inputting such reports on the SPA-Web site, management at all levels can get advantage of Internet-based communication in receiving and commenting on project progress. This real-time communication provides an excellent opportunity for brain storming and overcoming difficulties in a proactive, rather than reactive, planning and control manner.

5 SPA web site

Decreasing project life cycle and increasing cost of capital are compressing the time needed to design and construct complicated facilities within the SPA. At the same time, increasing technological complexity is shifting project control away from prime contractors towards specialized subcontractors. This is a trend, which suggests that the project management industry needs to consider the reengineering of how it processes and moves information among all concerned parties.

The SPA-Web site has given a new tool for reengineering the delivery of information on construction projects. This Internet-based tool allows geographically separated teams easy access to project specific information and documents, thereby streamlining traditional information flow. In an age of increasing complexity, such basic project Intranet can enhance communication and improve teamwork in the execution of rapidly developing construction projects.

As information changes, the server content can be easily updated with new or revised data. This flexible approach means that geographically remote project teams can access timely, consistent and accurate information without expensive typesetting, printing, distribution an mailing charges. The basic Intranet uses information that does not change rapidly. This simplifies administration and publication and acts as the stepping stone for a larger Intranet system.

In the SPA, this Internet-based tool has shown promise as a cost-effective way to improve the delivery of information. Thus, it improves teamwork, streamlines project schedules and reduces litigation with the end result of providing the customer with increased project satisfaction.

6 Information security

Because of the contractual nature of the construction business, many firms are afraid of losing control of the information they have developed. Fortunately, the open standards of Internet-based systems offer several ways to move and manipulate information. For example, a superintendent can use the browser to view the design files in a "read only" mode. Web-based applications such as Adobe's PDF format enable developers to publish documents that look just like the printed page. Similar to paper blueprints, this enables the user to look at the drawings and retrieve information, while leaving the control of the file with the original publisher. Given the increasing popularity of the Internet, most software applications are now being developed for Web publishing.

Webmasters can also set up servers to control access to specific parts of an Intranet. SPA-Web media is set up to allow public access to the project description and progress information, while restricting access to more sensitive parts of the web site. The project team has set up a matrix of access privileges to the project information.

7 Benefits

In a distributed questionnaire to all individuals using the SPA-Web media, many benfits have been reported including:

- Improve information accuracy and accessibility
- Enhance communications and teamwork between disparate teams
- Eliminate redundant files
- Eliminate multiple data entry tasks
- Provide multi-locations access to information
- Eliminate departmental and organizational ownership of information
- Improve process efficiency since communication uses less time & fewer resources
- Improve customer/ supplier relations
- Reduce dependency on paper based information
- Obtain accurate and timely reporting

8 Findings and conclusions

Good communication is critical in achieving better cooperation and coordination across organizations in the business world. In construction the project team consisting of the owner, contractors, designers, and other parties all need to work together to achieve common goals. The project team needs to communicate over the life cycle of the project efficiently (i.e., with minimum time and resources) and effectively (i.e., different parties receive same interpretation).

Using the SPA-Web media, the communication efficiency between the SPA and the A/E and the contractors is improved significantly with a reported time saving of more than 80%. In addition, the communication effectiveness is improved by minmizing any misunderstanding or misinterpretation by the different parties. The SPA-Web media also reduced the indirect cost by saving paper usage, phone and fax charge, postal cost and information processing time. Perhaps, most important result is the reduction of claims resulting from delay in receiving information and misinterpretation. This new media speeds up information delivery, improves information accuracy and contributes to the total value management of construction projects.

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218 INCREASING ON-SITE PRODUCTIVITY THROUGH WIRELESS COMPUTER CONTROL

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Abstract

Improving productivity has been a major objective of the building industry, and indeed in all forms of business for many years. The construction process involves many complex processes, which make it inherently difficult to manage and can obviously lead to much inefficiency within the process. It is possible for a wireless communications system to be adapted for use on construction sites in order to improve management control over tasks and communication between parties involved in the project. This feasibility study shows that the implementation of such a system could lead to significant time savings over traditional paper-based management and administration systems.

Keywords: Productivity, Site, Wireless, Control, Construction, Computer, Data

1 Introduction

Improving productivity has been a major objective in all forms of business and industry as technological development has accelerated more and more rapidly over the last decade. Computer control has been applied to the manufacturing industry with great success and is being continuously refined, to bring higher efficiencies in design, production and delivery of goods. It is the repetitive nature of the processes within this industry that lend themselves to computer control. The construction industry however, often involves complex, one-off projects, with many variable processes and so requires a more flexible system of control. Applying information technology and control systems to this industry, with its unique nature, requires adaptation of existing technologies to suit its own specific (but not entirely dissimilar) requirements.

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Studies (Horner et al. 1996) have shown that the potential for increase in labour productivity in the UK construction industry may be more than 25%, and that large inefficiencies arise mainly from interruptions between activities and processes as well as delays within individual operations. These interruptions are often a result of poor planning, insufficient design information and supply-chain problems. A system that could enhance co-ordination and communication whilst providing ready and rapid access to relevant data would go a long way towards reducing many common on-site delays of this nature.

Attention has recently been focused on regarding construction as a process rather than as a series of discrete functions. It is improving continuity of the construction process that is of greatest importance in the on-going quest for greater efficiency. Integrated computer control systems, which could cover all stages, from the conception and development of a design, through completion of a building, seem to be an obvious choice in aiding this development. This is a huge area of study and this feasibility study report focuses on site processes only, developing a model for computer control, which will incorporate wireless technology in an attempt to smooth the transitions between complex processes and improve general productivity on construction sites. The system will in essence allow traditional office based tasks, access to information and information flow between parties, to be performed virtually anywhere, through a mobile communications system.

2 Wireless technology

Wireless Local Area Network (WLAN) technology uses electromagnetic waves (radio or infrared) to communicate information from any location without relying on any physical connection. The data being transmitted is superimposed on the radio carrier so that it can be accurately extracted at the receiving end (http://www.cwc.nus.sg/) WLAN must not be confused with other wireless systems such as mobile phones, and data transmission over cellular or packet radio. These systems require costly infrastructure, provide much lower data rates, and require users to buy bandwidth on time or usage basis. On premise wireless LAN requires no usage fees and provides 100 to 1000 times the data transmission rate (http://www.cwc.nus.sg/).

Mobile communications technology has seen major growth and development over the last few years and continues to advance as on-the-move applications become more widespread. Wireless data technologies have been proven through more than fifty years of application in commerce and by the military. Robust designs of proven WLAN technologies and the limited distance over which signals are required to travel result in connections that are far more robust than cellular phone connections and provide data integrity performance equal or better than wired networking (Hills et al. 1996).

Many construction companies have 'computerised' in recent years, with most businesses using computers to store information or perform tasks for varying proportions of their operations. A recent survey has showed that 83% of decision makers in the industry have access to a personal computer (Cole 1997). The issue now is *access* to this information. The availability, ease and speed of access to information and the efficiency with which this can be used is now often what will set one company apart from another. Mobile communication technology is a tool for a potentially more advanced form of communication allowing spoken/written word and image to be sent and accessed more freely than ever before. The possibilities of mobile communications technology have only just begun to be explored as applications for this new technology is gradually realised. For example, Newton mobile computers have already been applied to many small and large businesses and also parts of the healthcare system in both America and France. More comprehensive prototype systems have been tried in the Bellevue police force near Pittsburgh, various hospitals across America, and AEG's Daimler-Benz maintenance and engineering feedback system (for more case studies see web site:http:www.wlana.com). These industries have profited from productivity gains of using hand-held terminals and notebooks to access and transmit real-time information to centralised hosts for processing.

"The ability to access information on demand at any location confers distinct competitive advantage on users in an increasingly mobile world. As users become more dependant on this ability, the span of access of data repositories will have to grow. The increasing social acceptance of the home as a place of work is a further impetus to the development of mechanisms for mobile information access." Satyanrayanan (1996)

3 A construction site WLAN model

A construction site is usually contained in a small enough area to make use of a high-speed wireless WAN, allowing wireless devices to communicate rapidly from any part of the site. It is also possible to imagine a network structure which would link all parties involved in the construction process from architect, to main contractor, to sub-contractor and even to materials suppliers, providing a potential level of co-ordination and communication that has never been seen before. A radio communications controller linked to base stations located around the site would manage data traffic and also provide the link to the host computer (located in the site office). The host computer, hard wired into the LAN (e.g. BT Construct system) would be able to provide access to parties such as architects, quantity surveyors, engineers, etc. This network would allow direct access to all available design and construction data, through use of a mobile device anywhere on the site. Fig. 1 illustrates the proposed site infrastructure for a WLAN system. End users access the WLAN through wireless LAN adapters that are implemented as PC cards in notebook computers, ISA or PCI cards in desktop computers, or integrated within hand-held computers that can read bar codes and smart cards. As well as providing increased information access and management for use on site, the system should be able to facilitate all day-to-day construction tasks such as logging materials delivered, checking against materials specified and ordered. This would be achieved through a database, contained on the host computer being automatically updated remotely by a handled device as deliveries and other important data are entered by site staff. This system would eliminate much paper work, storage and retrieval time, checking and validating by hand. Material ordering could be co-ordinated by the host computer drawing on information within its database on programming, state of work in progress, material specifications.

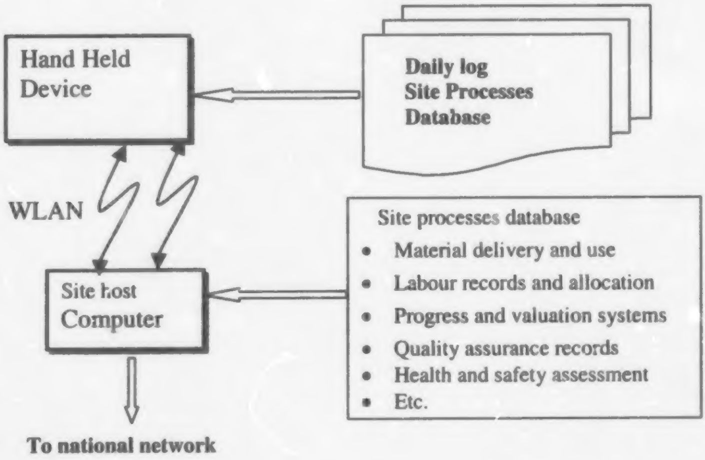
Hand Held Device
Daily log
Site Processes
Database
WLAN
Site host Computer
Site processes database
Material delivery and use
Labour records and allocation
Progress and valuation systems
Quality assurance records
Health and safety assessment
Etc.
To national network

Fig. 1: Site infrastructure for a WLAN system

An intelligent materials ordering system could do more than just aid the administrative process, but also prompt, check and advise, allowing much tighter resources management from site and head office to see if site is on progress. Deliveries could be logged using wireless hand-held devices, and information sent to the host computer which would check against the ordered material, record delivery and trigger the payment process. As this technology becomes more common materials could be labelled with easily accessible bar codes for even more efficient scanning and logging as they arrive on site. Availability of up-to-date design information, control over actual work in progress and collection and recording of information relating to work in progress are important factors in maintaining quality construction. Collecting, co-ordinating and processing information on site processes is a relatively lengthy process and involves several stages of recording, checking and processing which often leads to unnecessary errors. A mobile wireless network could allow immediate access to constantly updated design information, and allow users to remotely access and log data, reducing delays caused by waiting for information and manual recording of site information.

The site system would hold a database of all relevant plans and performance specifications relating to the particular project. Any variations, new drawings, design information etc. are logged and updated automatically by communication with the consultant through the LAN. The site system database can be checked remotely by a hand-held device, so that users can check data such as measurements, quality assurance documents, health and safety assessment forms and specifications, and other relevant site documentation, ensuring that work in progress conforms to specifications. Logging of operatives on site, day work sheets, adherence to programme, notes to consultants and personal reminder notes could all be entered via a hand held device from anywhere on site. The benefits for a busy site co-ordinator are obvious, with speed of access-to, and recording-of information made faster and easier, reducing delays and mistakes. Additions to the system to improve it's usefulness could include audible reminder notes and pre-set prompts linked with the site-diary, calendar and construction programming functions. Survey data obtained using a computerised system equipped with GPS (global positioning system) could be used to facilitate setting-out through integration with the wireless computer network. Regular valuations are essential both for the contractor (in order to calculate cash flow) and for monthly payment by the client to the contractor. Computerisation of the interim certificate system, allowing data regarding payment to be sent to various parties electronically, should increase control over, and speed up the monthly payment process. A computerised measuring process would also be possible by way of a hand held device. Using this device the quantity surveyor would be able to walk around site, entering progress data on the spot through the use of database and plan-view software. The system possibilities are endless.

4 Field survey

In order to estimate how useful a wireless communications system might be in use on construction sites, a questionnaire has been used to try to gauge the savings that might be made in certain areas, were it to be installed, and some factors which might influence the choice of the system over traditional methods. The questionnaire was sent to fifty construction companies, both large and small in an effort to quantify how much time is spent on site administration processes which might be benefited by the system, and any possible increases in efficiency which may result from a wireless-based approach.

The questionnaire posed three questions. The first question required the respondents to estimate how much time was spent on--site each day performing the following operations:

- materials ordering
- checking materials on delivery
- invoice validation and processing
- recording and processing day work
- handling and processing variations
- correspondence with consultants

- correspondence with sub-contractors
- waiting for design information

The recipients were asked to indicate for each operation, a time, which they felt appropriately described how much time was taken up on-site. Choices rose in increments from 10 minutes to 5 hours per day. The second question required recipients to estimate how much time they considered the system could save. The same operations were listed as in question one, but this time the answer was expressed as a percentage time saving. Choices were between 0 and 100% with a 'don't know' option included. The estimated productivity improvements are based on a limited broad knowledge of the system with a limited idea of its scope. Question three required recipients to rate the following factors in order of importance in the choice of a wireless communications system over a more traditional site administration approach. It was hoped that this would give some idea of the viability of the system while at the same time trying to gauge how willing contractors would be to implement change.

- set-up costs
- training and familiarisation
- reduction of mistakes and errors
- efficient information storage and retrieval
- quick, on-the-spot access to construction information and records
- intelligent construction programming and materials handling
- overall productivity gains
- potential for easier and improved communication between consultants sub contractors, etc.
- potential for long term competitive advantage

5 Survey results

Estimated duration and productivity improvement is depicted for each operation. From this, typical duration and time savings are estimated for each operation. The findings of the survey are as follows:

5.1 Materials ordering

Figure 2 shows that estimations of time spent ordering materials each day varies from 10 minutes to 3 hours but by far the greatest agreement was in the 30 minute bracket. Estimated time saving of between 25-50% suggest that 5-15 minutes would be a typical saving each day under a mobile communications system.

5.2 Checking materials on delivery

Figure 2 shows that estimated time spent checking materials on delivery is very similar to answers given for materials ordering i.e. 30 minutes average. However, estimated time saving is viewed by most to be greater using bar-coding systems etc. Savings would seem to be in the order of 15-20 minutes per day.

5.3 Invoice validation and processing

Some respondents claimed invoice validation. was performed at head office and therefore not relevant. However, over half of the respondents estimated a 25% productivity improvement giving a saving of around 15-30 minutes per day as indicated by Fig. 2 and 3.

5.4 Handling and processing variations

Estimated duration range from 10 minutes to two hours as shown in figure 2. A large proportion of respondents estimated a 25% productivity saving which suggests time savings of between around 10-30 minutes per day (see Fig. 3).

5.5 Recording and processing daywork

Results show estimations of between 10 minutes and one hour for administration involving daywork. Figure 3 shows a typical time saving of 10% suggesting improved efficiencies in the order of 5-15 minutes per day.

5.6 Correspondence with sub-contractors

The majority of answers as represented by figure 2, indicate that time spent on correspondence with subcontractors is between one and two hours per day. An average estimated saving of 10-25% suggests savings of around 20 minutes per day.

5.7 Correspondence with consultants

Results for estimation of time spent and possible savings in correspondence with consultants is very similar to that for correspondence with sub-contractors. Typical time saving could be around 10-20 minutes per day (see Fig. 2 and 3).

5.8 Waiting for design information

Estimation of delays relating to inadequate design information range from 10 minutes to 2 hours per day but indicate that little improvement is expected in this figure. A large number of answers indicate 0% improvement but others suggest that the potential for improvement could be as much as 75%. An estimated 15minute saving per day is a fair representation of the results.

6 Implications

It is obvious from these results that the marginal time savings in each activity represent a substantial collective daily time saving and an even more impressive saving when projected over a year as has been represented in Table1. Opinions about how effective the system may prove to be are varied amongst the recipients of the questionnaire but whatever the magnitude of the saving may be, the cumulative effect over time would appear to be significant (an average of 40 days per savings).

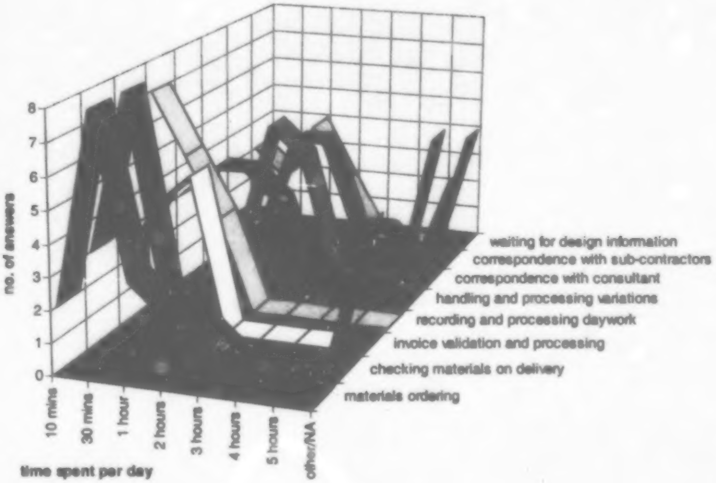

Fig. 2: Time spent on site

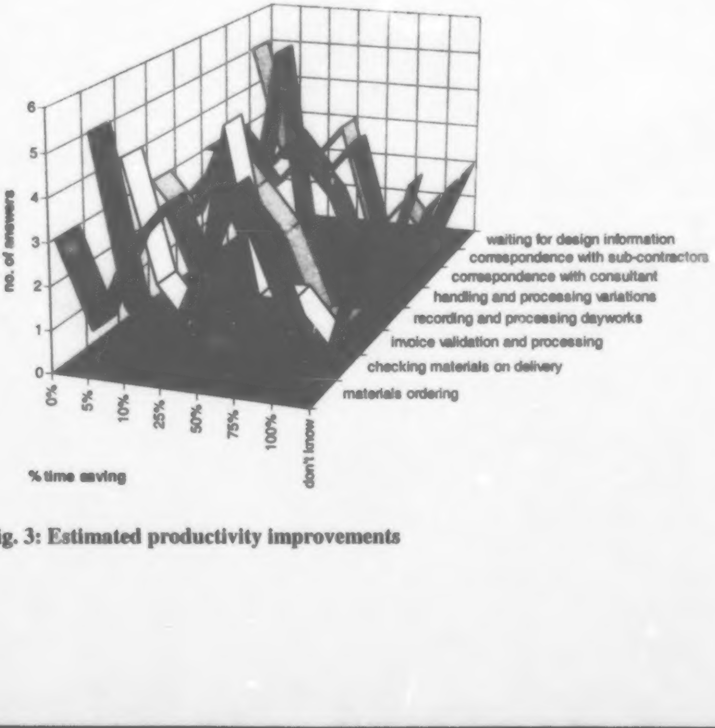

Fig. 3: Estimated productivity improvements

Table 1: Estimated productivity improvement

	Max. time saving	Avg. time saving	Weekly time saving (mins.)		Annual time saving (mins.)	
	minutes/day	minutes/day	max	average	max	average
Materials Handling	15	3	82.5	16.5	4042.5	808.5
Checking materials on delivery	15	5	82.5	27.5	4042.5	1347.5
Invoice validation and processing	30	15	165	82.5	8085	4042.5
Handling and processing variations	30	10	165	55	8085	2695
Recording and processing daywork	30	10	165	55	8085	2695
Correspondence with sub-contractors	60	20	330	110	16170	5390
Correspondence with consultants	30	10	165	55	8085	2695
Waiting for design information	60	15	330	82.5	16170	4042.5

Total minutes	270	88	1485	484	72765	23716
Total hours	4.50	1.47	24.75	8.07	1212.75	395.27
Total days					**121.28**	**39.53**

Note: calculations based on a 10 hours/day, 5.5 days/week and 49 weeks/year

7 Perceptions of the system

The third question was included in the questionnaire in an attempt to try to gauge how ready contractors might be to install such a wireless communications network on site in practice. Fig. 4 shows that the main factors that contractors are likely to take into consideration are long term competitive advantage and storage & retrieval capabilities, with factors such as set-up costs appearing down the list. Opinions vary mainly according to company size obviously, as the economics of such a move will work in the favour of larger contractors.

8 Conclusion

The field survey results demonstrated that a wireless-based approach would be both possible and beneficial to the construction industry. The results of the survey indicate that *time savings in the order of 40 - 120 days per year* could be possible if the system was to be applied. Above all these results show that the use of this new communications technology could be of great benefit to the industry heralding a leap forward in communication during the construction process and that such technology should not be discredited or ignored.

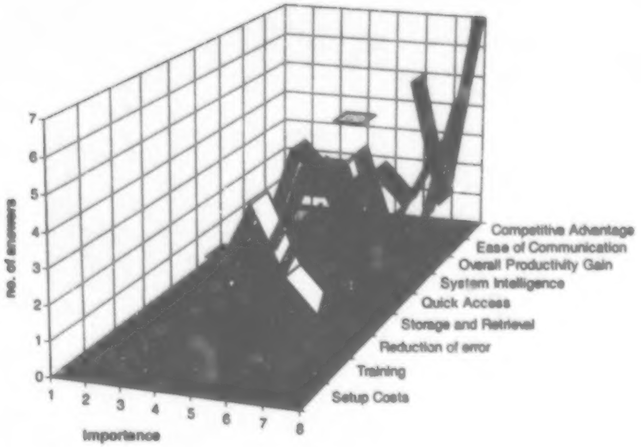

Fig. 4 Factors considered in implementing wireless technology

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219 SIMULATION OF CONSTRUCTION OPERATION WITH DIRECT INPUTS OF PHYSICAL FACTORS

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Abstract

The deterministic approach to estimating the production rate of a construction operation assumes constant midpoint physical attributes without addressing the effect of randomness of job conditions. On tne other hand, most simulation models bypass physical factors and rely on second-order inputs of probability distributions of task times, the judgements of which have been cited as difficult for users to make. This paper presents an alternative approach to production estimation, based on simulating directly the effects of changing job factors on task times, while addressing the probabilistic nature of construction. The neural network model is used as the computing mechanism for determining the cycle times of the equipment in given conditions and provides the basis for estimation. The obtained times are then fed directly into a discrete-event simulation model to simulate the process and establish the production capacity of the system as constrained by first-order factors. The approach is illustrated using a hypothetical excavating and hauling operation while the object-oriented programming technique is used to implement the computing procedure.

Keywords: construction productivity, excavation operation, neural network, discrete event simulation, object oriented programming

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1 Introduction

The maximum production rate that can be achieved for an on-site mechanised construction operation is dependent on the production capacity of the set-up of the employed equipment resources working in the given physical environment. The estimate of this capacity will be the basis for the expected speed of the operation which is obtained by applying further a percentage efficiency factor to reduce the maximum rate. The result is then used in cost and time estimation for the involved project.

The scope of the current paper is to study methods for estimating the above-mentioned maximum capacity as constrained by physical job factors only, without considering non-physical or management factors that influence operation efficiency. Existing estimating methods are reviewed and commented before a proposed method is presented, which is based on neural network models for computing task times from physical factors while embedded in discrete event simulation. The common excavation and hauling operation is used throughout the discussion and comparison of the methods.

2 Existing estimating methods: deterministic vs. stochastic

The traditional deterministic method is most commonly used for production estimation for construction operations. With this method, fixed average job conditions are assumed even though the conditions encountered are changeable. The production capacity of the leading resource of a system is usually first estimated according to such assumptions to determine the output rate of the set-up which includes other resources that work together.

For example, in an excavation and hauling operation which employs an excavator and a fleet of trucks, the excavator is the leading resource whose digging capacity determines the number of truck loads that can be produced at most. Since the excavator's maximum hourly production depends on the number of digging cycles achievable per hour, its average cycle time for the job needs to be estimated first. With the deterministic method, midpoint values of work dimensions and conditions, i.e. average depth of cut, average swing angle, average soil properties are assumed and used in estimating the average cycle time and thus the production rate. Similarly, fixed haul conditions are assumed in estimating the average truck travel time for determining the system production for a given number of trucks.

If considering the overhead time spent by the excavator repositioning itself after each truck load, the deterministic estimates of the production capacity of the operation can be obtained as follows:

$$X_{max} = \frac{60}{T_l + T_r} \times V_t \qquad \text{(when } N > N_b\text{)} \qquad (1)$$

or

$$X_{max} = \frac{60}{T_l + T_r} \times V_t \times \frac{N}{N_b} \qquad \text{(when } N < N_b\text{)} \qquad (2)$$

where X_{max} = operation production (m^3 per hour)
T_l = loading time per truck (minutes)
T_r = excavator reposition time after each truck load (minutes)
V_t = volume per truck load (m^3)
N = number of trucks
N_b = balanced number of trucks

Further, T_l and N_b can be obtained as follows:

$$T_l = \frac{t_c}{60} \times \frac{V_t}{V_b} \qquad (3)$$

$$N_b = \frac{T_t + T_l}{T_l + T_r} \qquad (4)$$

where t_c = average digging cycle time (seconds)
V_b = bucket volume (m^3)
T_t = average truck cycle time (including spot time, hauling time, dump time, and return time but excluding loading time, minutes)

More details on the deterministic method can be found in many publications such as Nunnally (1987), Caterpillar (1988), and Gransberg (1996). Despite its wide use, one acknowledged important problem with the above method is that it ignores the effects of changing job conditions and random task times, which are prevalent in real situations, and at times this might lead to inaccurate results.

To better model the randomness existing in construction operations, many researches have suggested stochastic simulation based methods and programs, which often are intended for general uses instead of a particular type of operation. Using such packages to estimate an operation's production will require inputs of probability distributions of task times, relations among tasks, and types and numbers of resources. During a simulation run, task times are sampled from the inputted distributions and events are generated through the period of the operation to accumulate productions and compute various statistics. For more about such discrete event simulation models, see McCahill and Bernold (1993).

The critical information needed for using the above general purpose simulation method is the probabilistic task times which are determined by the user based on past data. The model itself is not concerned with the influence of physical job conditions (or first order factors) such as work dimension and soil type on task times (or second order factors). Its ability to deal with closely the relation between first and second order factors for a particular operation has to be sacrificed in order for it to be general, but the user will in the same time lose the feel of the impact of first order factors on the final results. This problem has been cited as hindrance to wider use of simulation models (Schexnayder 1997).

3 Proposed method: simulation with physical factors

As an alternative approach to estimating an operation's production capacity, the proposed method is based on computing directly the effects of physical factors on task times meanwhile simulating the work flows of the employed resources to establish the production rate. Since the exact job conditions change constantly in a random manner and the speeds of equipment resources will vary accordingly, the probabilistic nature of production in the construction environment is addressed.

To cater for the special attributes of each task involved in a particular type of operation, certain computing mechanisms will have to be developed as the basis for estimating task times. They will be embedded in the discrete event simulation program as modules to be called by the main procedure when tasks are enacted. For reasons of computing efficiency and complex mapping ability, it is suggested to use the neural network model as the common mechanism to provide task times in given conditions for the simulation process. Each task will require a neural network pre-trained on observed performance data for the employed equipment to perform the following mapping function:

$$(x_1, x_2, \ldots, x_N) \Rightarrow T \tag{5}$$

where $x_1, x_2, \ldots, x_N$ = parameters for physical job conditions
T = task time

For example, the neural network model's input parameters for an excavator will be depth of cut, angle of swing, and type of soil, while its output will be excavator digging cycle time. The neural network model's input parameters for a truck will be gross weight, total resistance (grade plus rolling), and travel distance, while its output will be truck travel time.

Training data for a neural network can be obtained from site observations of equipment performance or from the manual prepared by the manufacturer for that particular model of excavator or truck. Details of developing a neural network model

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for estimating productivity of construction equipment can be found in Chao and Skibniewski (1994).

For reasons of system modularity and flexibility, it is suggested to use the object oriented technique to implement the system design and develop the simulation programs. In such programs, each task and resource of an operation is represented by an object which is a combination of relevant data and functions. In the case of typical excavation and hauling operations, the simulation system developed in C++ will include the following components:

- a main function that initiates the attributes of a job, creates the objects for the job, contains the simulation algorithms, and outputs the results
- an excavator object that includes the excavator's characteristics and a function for estimating its digging cycle time for given digging parameters
- a series of truck objects that each include a truck's characteristics and a function for estimating its travel time for given haul parameters
- truck-loading task objects that each include the excavator and truck objects concerned, the excavation attributes, and a loading time estimating function

The structure and weights of a neural network trained for an excavator or truck for cycle time estimating will be imported from an external file by the excavator or truck object concerned. For more about developing an object oriented application for estimating task times in construction, see Chao (1998).

Due to the randomness introduced in the simulation process, each independent run of an operation will result in a somewhat different production rate achievable, and hence a large sample of, say, 100 runs should be obtained to find out the average production level as the estimated operation capacity. The method presented above is illustrated using a numerical example of the excavating and hauling operation in the following.

4 Illustrative example

Assume the scenario of an excavation and hauling operation with a medium size hydraulic excavator digging in medium job conditions and loading a fleet of off-highway trucks one by one which will then travel individually to a dump to dump the load and travel back for another load. The model of the trucks used has an empty weight of 31 ton and a maximum gross weight of 67 ton. The excavator's features and a summary of the job conditions are shown in Table 1 and Table 2, respectively.

Table 1: Features of excavator

Heaped bucket capacity	1.7 m3
Maximum depth of cut	5.8 m
Width of undercarriage	3.0 m
Optimum horizontal reach	5.5 m
Maximum horizontal reach	8.0 m
Effective reposition speed	0.15 m/sec
Set-up time per reposition	10 sec

Table 2: Job conditions of example excavation and hauling operation

Depth of excavation (m)	3.6
Type of soil	II (common earth)
Unit weight of soil (kg/m3 in bank measure)	1840
Load factor of soil	0.80
Bucket fill factor of soil	0.80 - 1.10
Haul distance (m)	1600
Total resistance of haul road to dump (%)	12
Total resistance of haul road to excavation (%)	3

The excavator will finish the excavation in strips of equal width while being positioned on the bench with bench height equal to the depth of the excavation. During digging and loading it will have its front facing the work zone, the width of which equal to its undercarriage width in order to minimise the swing angles from cut locations to the truck positioned on one side of the excavator. After each truck load the excavator will move backward to reposition itself and start another truck load.

The cut location for each digging cycle will be set randomly within the work zone so that all locations have equal chance to be reached. The swing angle and depth of cut that defines a cut location will vary accordingly to the effect of changing digging cycle times and truck-loading times.

Since exactly how much material contained in each bucket load is uncertain, the bucket fill factor is assumed to vary randomly within the range shown in Table 2. The work volume (m3, bank measure) completed in a digging cycle will be calculated as heaped bucket capacity times bucket fill factor times load factor, with an average of 1.29 m3.

Consequently, the volume of a truck load, which needs 15 buckets to fill it, will not be a definite number but vary accordingly. The changing gross vehicle weight will lead to a different truck travel time to the dump.

Based on the considerations described above and the concepts presented in the previous section, the required modules of a simulation program can be developed to solve the production estimation problem for the given job conditions as well as other similar operation scenarios. The common back propagation algorithm can be used to train the two neural networks embedded in the program.

Training data for the neural networks in this example was obtained from Nunnally (1987) and Caterpillar (1988), for excavator cycle times and truck travel times, respectively. A summary of the characteristics of the two neural networks developed is shown in Table 3.

Table 3: Summary of neural networks used

Network Attributes	**Excavator cycle time estimating network**	**Truck cycle time estimating network**
No. of training sets	72	52
No. of hidden layer nodes	8	11
No. of training cycles	12000	18000
System error	0.000012	0.000012
Average error	0.67%	0.94%
Maximum error	2.31%	2.81%

For the given job conditions (work zone width of 3 m, maximum depth of cut of 3.6 m, and type II soil), the frequency distribution of the excavator's digging cycle times produced by the neural network model is shown in Fig. 1. For cut locations throughout the excavation, the cycle times range from 16.5 to 20.5 seconds, with a mean of t_c = 18.3 seconds and standard deviation of σ = 0.81 seconds. The average loading time per truck calculated using (3) will then be T_l = 4.6 minutes.

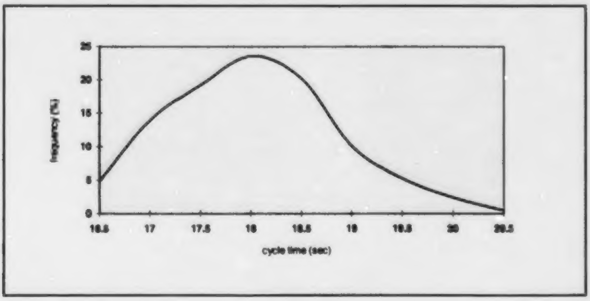

Fig. 1: Frequency distribution of digging cycle times

Assume that each truck load requires the truck to spend a fixed time of 1.8 minutes in manoeuvring and dumping and that the operation runs continuously for 210 minutes (3.5 hours). The average hourly production from 100 independent simulation runs is taken as the estimated capacity of the system that employs a certain number of trucks. As shown in Fig. 2, where the results are plotted against the numbers of trucks used ranging from 1 to 10, the production level achieved when a sufficient number of trucks (more than 3) are employed is around 236 m3 per hour.

A comparison of simulation versus deterministic estimates is also shown in Fig. 2. While the former is based on all cut locations and a changing bucket fill factor, the latter is based on the midpoint of the work zone and excavation depth and a fixed bucket fill factor, which result in a digging cycle time of 17.8 seconds, a truck loading time of 4.45 minutes, a truck cycle time of 11.1 minutes, and a system capacity of 241.3 m3 per hour. For this example, the deterministic method over-estimates the productions consistently because it under-estimates the task times needed.

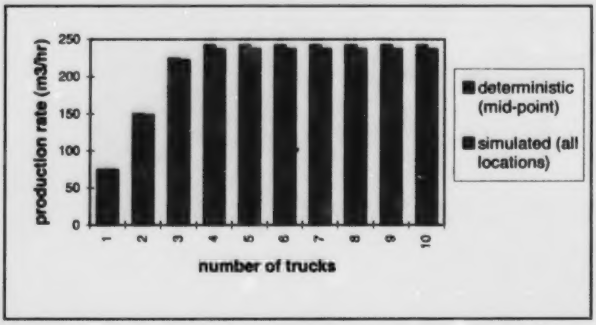

Fig. 2: System production estimates

5 Conclusions

A neural network based simulation method for estimating the production of a construction operation is presented. The objective is to establish the system capacity as constrained by first-order factors. Because of the tedious and complex calculations involved, the traditional deterministic method uses simplifications for a short cut to the solution which sometimes will lead to inaccuracy. A more realistic estimation is made possible with the use of neural network computing within the framework of discrete event simulation while developed using the object oriented technique. As shown in the illustrative example, a complex real world problem involving many variables becomes tractable. However, such programs will have to be built specially for a particular type of operation, because the performance of various types and models of equipment in construction is influenced by a variety of physical parameters in unique ways.

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220 ANALYSIS OF PHENOMENOLOGICAL PERCEPTIONS OF EFFECTIVENESS OF INFORMATION TECHNOLOGY IN COMPUTERISED MAINTENANCE MANAGEMENT

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Abstract

The general aim of this empirical research was to examine the phenomenological perceptions of both asset managers and support or ancillary staff using qualitative and quantitative analysis for the purpose of assessing efficiency of information technology in a public sector building construction maintenance management environment, particularly to develop a framework technique that will be useful to investigate such fundamental phenomenological facets as efficiency of training and information technology, the effect of information technology on human relations within the workplace, the perceived impact of information technology on the efficiency of occupational performance, and a summative evaluation of information technology in the asset management environment. Empirical investigation by structured interview with both management and support staff within a public sector asset management organisation was undertaken. The data was analysed through unpaired t-tests between asset managers and support staff, and dichotomous questions for experienced versus inexperienced employees and employees as differentiated by age. The results of the analysis revealed that both asset managers and support staff perceive information technology as beneficial in terms of both qualitative and quantitative outcomes. Further it would appear that individually at all levels within the maintenance management sphere exhibited phenomenological perceptions of information technology that were particularly favourable and overall were consistent with the conclusions of researchers who had observed information technology's benefits in terms of other quantitative and qualitative outcomes, in industry. Further research is suggested in the areas of customer satisfaction both prior to and subsequent to the implementation of more sophisticated information technology systems in addition to investigating the interaction between actual productivity levels and phenomenological perceptions of beneficial outcomes as a function of information technology.

Keywords: Phenomenological perception, efficiency, information technology, asset management, organisational change

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1 Introduction

Information technology is perceived by a multiplicity of researchers and practitioners within industry to be extremely useful in terms of increasing both quantitative and qualitative outcome factors (Mathews, 1994). It has been identified by Mathews as the fifth paradigm shift in the industrial revolution. "Information technology is having pervasive effects throughout the economy that are entirely analogous to the previous paradigm shift" (Mathews, 1994, p.84). This paradigm shift has resulted in the transformation of a plethora of existing organisations within the building construction industry. Mathews purports most programs of organisational change end up as failures. Accordingly this study focuses upon one evaluative aspect of information technology's implementation, namely,the phenomenological perspectives of both asset managers and support staff in terms of both qualitative and quantitative outcomes. More specifically this attitudinal research evaluated phenomenological perceptions with regard to computerised maintenance management in a large public building construction industry organisation in a number of diverse areas which have been demonstrated to be potential influences of both qualitative and quantitative output.

Additionally the research investigated managers versus support staff's attitudinal evaluations of information technology as this area is considered to be under researched, within the building and construction industry literature. Experience with the use of information technology in the building construction industry was also examined as a function of individual's phenomenological perceptions of information technology.

The initial fundamental area of importance investigated within the present research is that of information technology's effects upon human relations within the workplace for both asset managers and support or ancillary staff. Lansbury purported that in order to optimise information technology's benefits for management and support staff alike effective planning, consultation and implementation by management in co-operation with other employees is necessary (Lansbury, 1986). Australian Science and Technology Council's Report on "New Office Technology" (1986, vol 3, p.67) observed "the immediate office effects of the technology were judged more beneficial more frequently than were the broader 'organisational' effects". However this report focuses more on the quantitative output as apposed to information technology's effects on qualitative human relations. Areas examined within the context of this research include an investigation of information sharing between employees within the workplace, perceived level of control in completing duties, feelings toward information technology, fear of being made redundant and the perceived impact of information technology on chances of promotion. Gately, in an investigation of banking, retailing and data processing suggested a polarisation of skills levels would occur, as a result of the implementation of information technology (Gately, 1984). These observations could have a potential impact upon morale within the building construction industry also, if the results were generalised. Chishti, Martin and Jacoby claim, in a study of information technology's effects on a diverse range of Australian companies, that a "negative effect on the mental health and morale of employees was reported by a noticeable percentage of respondents"

(Chishti, et al, 1997, p.11). This is argued to support 'resistance to change' theories as organisational change may force members to move from their comfort zone and may impact on their mental health (Lansbury, 1983).

The second area of investigation concerns both asset managers and support staff's perceptions of adequacy of training in the use of information technology. Bodi states that "there is a gap in the training market in terms of providing a conceptual understanding of systems and how to use them for the organisations benefit" (Bodi, 1987, p.7). Obviously within the building construction industry there is a need to adequately train employees in the use of new information technology developments. Coleman and Joseph argue that Australian history at present does not have a high commitment to training, instead educational institutions are criticised for their failings in this area (Coleman and Joseph, 1986). Inadequate training or problems in handling job changes may interact with human-computer interface issues and visa versa, Bodi states that "A poor interface may undermine an otherwise well designed job" (Bodi, 1987, p.13). Hence the study aimed to investigate manager verses support staff's phenomenological perceptions of sufficiency of training, effective forms of training and adequacy of training in terms of new information technology developments.

The final area of investigation was that of examining whether or not a difference existed between management and support staff in terms of phenomenological perceptions of both the quality and quantity of output. Staff perceptions of quality of output, quality of customer service and quantity of output in relation to information technology were analysed.

In summary, each of these areas is crucial to an understanding of an individual's phenomenological perceptions of the relationship between information technology and qualitative and quantitative output. From this study it was anticipated that other research topics would become apparent, leading to an investigation of fundamentally important areas of the building and construction industry with regard to information technology.

2 Method

2.1 Subjects

Participants in the study include seventeen management staff and an equal number of support staff, identified through occupational duties (N=34). Participants were screened for age and occupational experience within a computerised maintenance management environment.

2.2 Materials

Materials used within the study include a questionnaire designed by the researchers. The questionnaire examined training, human relations and occupational performance as a function of information technology, utilising both a Likert type scale in addition to dichotomous response and short answer type questions.

2.3 Procedure

Participants were instructed to complete the questionnaire individually, followed by a structured interview, administered by one of the two researchers.

2.4 Results

Data was analysed utilising the unpaired t-test procedure, with independent statistical analyses being conducted to control the type one error rate at 0.05. The initial area to be investigated was the differences between management and support staff's perceptions of training in relation to information technology. It was observed that a significant difference existed between management and support staff's level of satisfaction and training for existing information technology ($t=2.811,p,0.05$), with a higher mean score observed for the management as opposed to the support staff, where a higher score is indicative of a greater level of satisfaction (see fig 1). Additionally, a significant difference was also observed between these two groups for satisfaction with training for new information technology implementations as they occur ($t=2.837$, $p<0.05$), with a similar direction of results to those reported for the previous analysis (see fig 2). It was also observed that averaged across management and support staff , 88.2% of subjects utilised new information technology introduced in the work place, as opposed to 11.2% who did not. However, once again averaged across subject groups, 64.7% felt they were not keeping up with new information technology developments, whilst 35.3% believed they were.

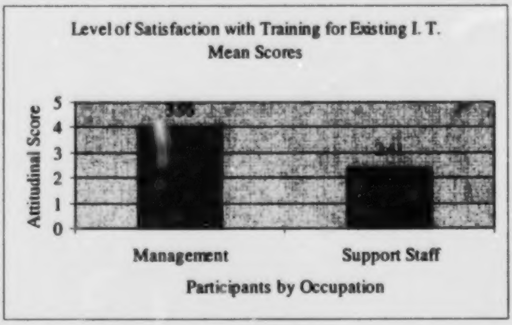

Fig. 1: Satisfaction with training for existing I.T

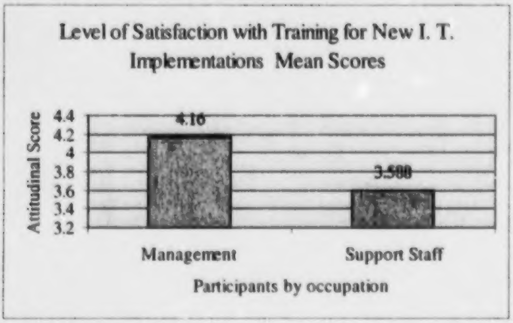

Fig. 2: Satisfaction with training for new I.T

The second area of investigation concerned that of human relations as a function of information technology, once again contrasting management versus support staff's phenomenological perceptions. The initial questions to be analysed concerned morale, with a significant difference being observed for the two groups perceptions of information technology's effects on office morale ($t=2.25$, $p<0.05$). Mean scores for managers were significantly greater than those observed for support staff, with higher scores evidencing greater satisfaction (see fig 3). A similar direction of results was observed for perceived control in occupational performance derived from information technology, with managers believing they had more control than support staff (see fig 4). This difference was also statistically significant ($t=2.604$, $p<0.05$). Finally, a highly significant statistical difference was observed between the two groups fear of redundancy as a result of information technology ($t=4.243$, $p<0.05$), with managers mean scores higher than support staff's, where high scores indicate a low level of fear of redundancy (see fig 5).

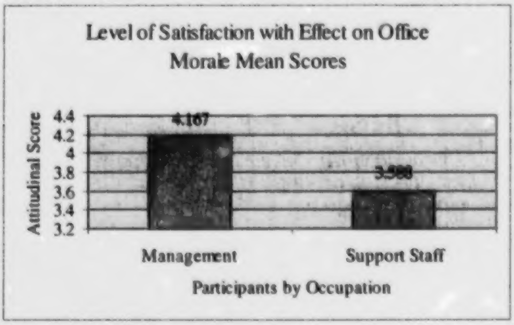

Fig. 3 Satisfaction with office morale

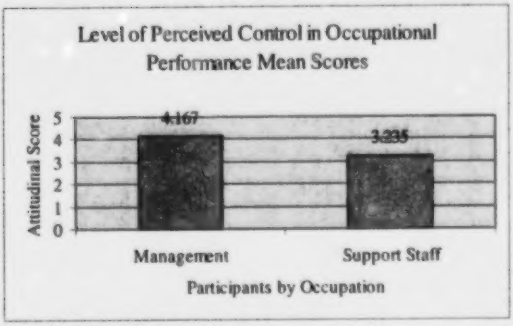

Fig. 4: Level of perceived control

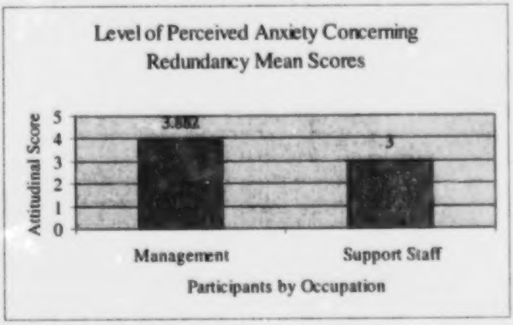

Fig. 5: Level of perceived anxiety concerning redundancy

The final analyses conducted utilising the t-test procedure involved differences in both groups perceptions of quality and quantity of service provided as a function of information technology. A statistically significant difference was observed between the two groups perceptions of quality of service provided as a result of information technology ($t=2.135$, $p<0.05$), with support staff demonstrating a lower mean score than management, where a low score is indicative of a perception of poorer quality of service being provided (see fig 6). In an analysis of quantitative output as a result of information technology, no significant difference was observed between management and support staff mean scores ($t=1.525$, $p>0.05$) (see fig 7).

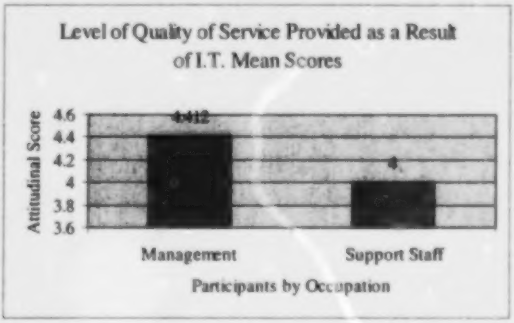

Fig. 6: Level of perceived quality of service

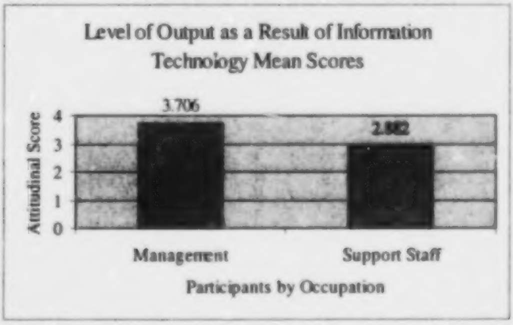

Fig. 7: Level of perceived output

Finally, in a dichotomous choice question evaluating information technology overall, averaged across both management and support staff, 82.3% reported they would use information technology over the old methods utilised, whilst 70.5% reported that they favoured the use of and introduction of further information technology within their workplace in the future. Exploratory investigation also took place with regard to the overall evaluation of information technology with regard to age of subjects, in addition to the years of experience of subjects being examined. It was observed that 60% of the older group of subjects favoured the use of information technology as opposed to 71.2% of younger subjects, while 50% of older subjects were in favour of the use of information technology in the future within the workplace as compared to 85.7% of younger subjects, where old refers to 40 years of age or greater.

With regard to years of professional experience, 63.2% of experienced subjects reported they were in favour of utilising information technology, as opposed to 73.3%

of less experienced subjects, where experienced refers to 10 years of experience or greater. While 57.9% of experienced subjects claimed they were in favour of the use of information technology and the further introduction of new information technology developments as opposed to 66% of their less experienced co-workers. All of the above analyses were averaged across management and support staff, with an investigation of their interaction envisaged in future research.

3 Discussion

Within the present empirical investigation a plethora of interesting results were observed, largely conforming with the theoretical hypotheses derived from previous research. However, the existent differences observed between ancillary staff and management's phenomenological perceptions of efficiency of training and information technology, the effect of information technology on human relations within the workplace and the perceived quality of output warrant further investigation as this could be an area of importance in terms of increasing the overall efficiency of information technology, through garnering support and satisfaction with information technology, from support staff in addition to management. A great deal of further research and investigation in the field is necessary within this area.

The initial area investigated involved the perceptions of both managerial and support staff toward training levels and information technology within a computerised maintenance management environment. It was observed that while mean scores were reasonably high for both groups on a Likert type scale, indicating to some extent satisfaction with training, a significant difference was observed between the two groups. The management group reported a higher level of satisfaction than did the support staff group. This could be an area of some concern, as the morale of the support staff may be affected, potentially resulting in lower levels of both quantitative and qualitative output. It is considered that this is an area that needs extensive further research in an endeavour to ascertain initially whether training levels truly are satisfactory, and secondly whether staff perceptions of training inadequacy are related to output levels. As outlined earlier a diversity of theoreticians have identified the importance of training in terms of maximising the qualitative and quantitative efficiency of information technology, in addition to postulating existent training is to some extent inadequate in terms of both current information technology in addition to training on new innovations in the area which are introduced within various workplaces. However little research has been conducted within the area in the building construction industry, and particularly within computerised maintenance management areas.

The second area to be investigated within the study involved the effects of information technology on support versus managerial staff's phenomenological perceptions of human relations within the workplace. Similar to the last area of investigation, a significant difference was observed between these two groups perceptions of the effect of information technology within this area. This disparity of opinion is interesting in that it may also have some significant effect on the level of production of support staff within the workplace, which could potentially be rectified by making the workplace more 'human friendly'. Previous researchers have observed that low morale in the office is correlated with a diversity of problems ranging from poorer productivity to instances of mental illness (Chishti et al, 1994).

Finally the results would indicate that managers feel that information technology results in superior qualitative output, in contrast to support staff's beliefs. This result corresponds with those observed in previous analyses in which management displayed a more favourable phenomenological perspective than support staff toward information technology overall within the workplace. However the lack of any significant difference in attitudes towards quantitative output is interesting in that it would suggest that while support staff do not necessarily like all of the effects of information technology, they still acknowledge that it enables them to produce a greater output than if they were utilising traditional methods. This result could be particularly useful in terms of illustrating that further education and training may be useful in order to gain complete acceptance of information technology by support staff, following which both qualitative and quantitative output could be monitored.

The examination of age and years of experience in relation to information technology also provided interesting directions of results, but it is acknowledged within this study that further and more extensive examination of these areas is necessary, employing a more rigorous quantitative method than dichotomous answer type questions. Future research would be required to explore, more fully, the areas identified within the present study. It must also be recognised that further research in a plethora of diverse areas could also be undertaken. Including the investigation of such facets as looking at customer satisfaction in the building construction industry and its interaction with information technology, and as previously mentioned the degree of interaction between phenomenological perceptions and actual productivity as a function of information technology.

In conclusion, it must be recognised that while both support staff and management perceptions of information technology were reasonably high in terms of training, human relations and overall qualitative and quantitative output, a significant difference was evident between these two groups, in terms of satisfaction with information technology on the whole. While the high degree of satisfaction concurs with a multiplicity of previous researchers findings, the differences between the groups warrants further investigation to ascertain a more comprehensive understanding of the exact state of affairs within the building construction maintenance management sphere.

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221 I.T. SURVEY WITHIN THE CONSTRUCTION INDUSTRY OF HONG KONG

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Abstract

This paper presents results taken from a 1998 postal survey of the consulting firms and the contractors of the Hong Kong construction industry. The survey included, as one part of the four-part survey instrument, the 'Health Check of the Strategic Exploitation of I.T.' developed by the UK Centre of Excellence for Construct IT (Betts and Shafagi 1997). This paper present the results of the IT health check for a population sample of three hundred and sixteen contractors and another population sample of two hundred and seven consultant firms operating within the Hong Kong Special Administrative Region of China.

Keywords: construction, information technology, Hong Kong

1 Introduction

This paper presents results taken from current research into the extent that construction IT is used by the contractors and the consultant firms of the construction industry of Hong Kong. The research findings are one element of a postal survey of the contractors on the public works list of contractors, and also one element of a separate postal survey of the consultant firms listed in the Government directories of consultants. The list of the contractors, and the directories of the consultants, are administered by the Government of the Hong Kong Special Administrative Region (HKGSAR) for the competitive and open bidding of public works contracts and assignments.

This paper presents results from a common element of both surveys, namely a questionnaire published in 1997 by Betts and Shafagi and called by them, 'A Health check of the Strategic Exploitation of IT'. It is used to provide a comparative assessment of the strategies of the public works contractors of the

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Hong Kong construction industry for the use and deployment of IT: and similarly for the consultant firms that have expressed interest in carrying out public works commissions offered by the HKGSAR. The Betts and Shafagi questionnaire was first used in the UK but has also been used in Australia (Stewart et al. 1998), and in South Africa (Allen 1999). Further use in other countries is useful as it permits benchmarking on an international scale of this aspect of construction-IT.

The first of the two postal surveys is targeted at a population sample of 316 contractors. The sample ranges from small, local, businesses to large, international, companies. The second postal survey is targeted at a population sample of 207 consultant firms. This sample ranges from small, local, businesses to large, international, consultant organisations that use a mixture of offshore and onshore expertise.

2 Postal survey of Hong Kong contractors and consultants

The method developed by Betts and Shafagi is a self-assessment questionnaire of twenty-eight questions that companies answer to assess their use, and their management, of IT. The questions are grouped into three categories:

- the position of IT within the competitive business strategy of the organisation *(7 questions)*;
- the overall role of IT within the organisation *(5 questions)*; and
- the current IT strategy within the company *(16 questions)*.

The approach is useful to the companies who participate in the survey, because it gives them an instant feedback on their strategy and policies for the use of IT compared to a benchmark standard developed in the UK for this purpose. It is also useful to the researcher as it provides a basis for comparison with research exercises using the same survey instrument that have been carried out elsewhere. Or in this Hong Kong case: one sector of the industry compared to another. It should be noted that the questions in the health check are qualitative and not quantitative. The responses are useful indicators of the construction industry's self regard for the strategic importance of IT.

2.1 Analysis methodology

Scoring for each question is consistent with the method used by Betts and Shafagi, and adopted by Allen, and also by Stewart to enable international comparisons to be made. Answers are given a score of 1 for a 'D', 2 for a 'C', 3 for a 'B' and 4 for an 'A'. For the purposes of later analysis: a mean score between 0 and 1, is considered a 'D'; a mean score between 1 and 2 is considered a 'C'; a mean score between 2 and 3 is considered a 'B'; and a mean score between 3 and 4 is considered an 'A'. A small number of participants were unable to complete all of the questions in the health check. To remove any bias in the results, the entire response from these participants was removed from the data analysis. The remaining responses were analysed, and the arithmetic mean, median, and mode for each of the questions; for the three groups of questions; and for all the questions in the survey were calculated. In these same combinations, statistical attributes were calculated to indicate the frequency distribution and the variability within the sample. The overall result for each company was correlated to the number of employees in the company. Results were also separated into those companies who had ISO9000 certification and those who did not. This enabled a side by side comparison of results to indicate a possible relationship between quality assurance and strategic use of IT. In addition the results were also analysed for certain sectors of the population sample.

In keeping with the qualitative nature of the survey, the categorisation of the overall grading derived from the analysis is: A means 'IT innovative'; B means 'IT active'; C means 'IT aware'; and D means 'IT unconcerned'.

3 Survey of contractors

3.1 Sample population

The sample population is taken from the list of approved Contractors, kept by the Professional Services Unit of the Works Bureau of the Government of Hong Kong. Their Technical Circular No 9/1997 (http://www.wb.wpelb.gov.hk/circular/index.htm) describes the HKGSAR rules for admission to the list. This is primarily a pre-qualification process which, when satisfied, allows a Contractor to submit a tender bid for the construction of public works projects. The Contractors are grouped according to their proven track record and their ability to finance construction. The groups are Group A, Group B, and Group C. Each group is able to tender for public works contracts whose value falls within certain limits which are periodically adjusted by the HKG. For example, Group A contractors are eligible to tender for contracts not exceeding HK$ 20 million, Group B can bid for contracts up to $ 50 million, whereas Group C contractors can tender contracts of any value.

The Contractors are approved within one or more, of five categories of public works. These are: buildings (BD); port works (PW); roads and drainage (RD), site formation (SF), and water works (WW). The suitability of a contractor for inclusion in one or more of the categories and a particular group is assessed from the contractor's global business activity and construction activity in Hong Kong.

The approval assessment considers financial criteria, technical and management capabilities, and general evidence of being suitable to tender for public works projects within a group and for certain categories. There is not a requirement that Contractors must be of a minimum size of company. The nature of construction and the high degree of sub-contracting that takes place in construction in Hong Kong make this an imprecise measure of the capability of a company. However, it is a requirement that they employ in Hong Kong, a minimum number of full time management and technical personnel with relevant experience and recognised qualification in engineering and project management. A holding company and its subsidiaries can be included in the Contractors List, however they must give an undertaking that only one company will tender for one contract.

The Works Bureau of HKGSAR provided a set of data taken from their computerised list of public works contractors. The population sample from this list is 829 general contractors, 1636 if it included specialist contractors. The list was culled to remove specialist contractors who operate within a field so narrow that it does not represent the industry in general. Companies not registered in Hong Kong or joint ventures were also taken out of the population sample. The attributes of the culled Contractor population sample are itemised on Table 1. One company went into liquidation, resulting in population sample for the postal survey of 316 contractors.

Table 1: Attributes of the contractor population sample in general

Attribute of the population sample
Of the 317 Contractors in the population sample, 317 (100%) are listed in terms of Category and Group.
Of the 317 Contractors in the population sample, 125 (39%) have ISO 9000 certification.
Of the 129 Group C Contractors in the population sample, 103 (80%) have ISO 9000 certification.
Of the 88 Group B Contractors in the population sample, 15 (17%) have ISO 9000 certification.
Of the 100 Group A Contractors in the population sample, 7 (7%) have ISO 9000 certification.
Of the 129 Group C Contractors in the population sample, 21 (16%) are approved for all five Categories of public works.
(2 Group B Contractors also have five Categories, 0 Contractors are in Group A.)

3.2 Postal release of the questionnaire

The questionnaire was posted to the sample population on Saturday, February 28, 1998. The postal distribution followed commonplace rules to encourage participation. The deadline set for receipt of response was March 20, 1998. The percent level of response was measured and a list of responses created. Reminders were then issued and the registration process repeated for the second round of responses. A second reminder letter was sent out to remaining companies who had not responded. This reminder included a further copy of the questionnaire.

3.3 Results from the Hong Kong contractors

By May 8, 1998, 238 questionnaire responses were received. Incomplete responses to the health check survey reduced this to 194 for analysis. The 61% response is good for this type of survey. Average scores from each of the 28 questions, for the three major sections, and the responses overall were calculated using the marking methodology described in Section 2.1. The marks achieved are compared to the range of marks possible. For example, the range of marks in each of the question-sections, are: 0-28 marks for 'competition and business strategy; 0-20 marks for the 'role of IT'; 0-64 marks for 'IT strategy'; and 0-112 marks for the questions 'overall'.

Distribution statistics were computed, including standard deviations to measure the variability within the sample. These are listed in Table 2 to show the results for all respondents and the results for the A, B and C groups of companies, and also for companies with ISO9000 certification and those without certification.

The values at the higher end of each range indicate a higher priority is given to that aspect of IT within that sample sector.

Table 2: Statistical results from the Hong Kong postal survey of 194 contractors

All *(194 contractors)*	**High**	**Low**	**Median**	**Mode**	**Mean**	**SD**
Competition and Business Strategy	26	9	17	16	17	3.38
Role of IT	19	5	10	10	11	2.68
IT Strategy	63	16	33	30	34	8.43
Overall	101	32	61	60	62	13.08
Group A *(55 Contractors)*	**High**	**Low**	**Median**	**Mode**	**Mean**	**SD**
Competition and Business Strategy	26	9	17	16	16	3.41
Role of IT	19	5	10	10	10	3.01
IT Strategy	63	16	30	36	32	8.59
Overall	101	32	57	39	58	13.56
Group B *(59 Contractors)*	**High**	**Low**	**Median**	**Mode**	**Mean**	**SD**
Competition and Business Strategy	24	11	17	16	17	3.15
Role of IT	15	5	11	11	10	2.29
IT Strategy	53	20	33	37	33	7.24
Overall	92	39	61	51	61	11.31
Group C *(80 Contractors)*	**High**	**Low**	**Median**	**Mode**	**Mean**	**SD**
Competition and Business Strategy	26	9	17	16	18	3.4
Role of IT	19	6	11	10	11	2.64
IT Strategy	56	16	36	30	36	8.59
Overall	97	35	63	60	65	13.14
Contractors with ISO certification *(89 companies)*	**High**	**Low**	**Median**	**Mode**	**Mean**	**SD**
Competition and Business Strategy	26	12	18	16	18	3.24
Role of IT	18	7	11	10	11	2.4
IT Strategy	56	16	35	30	36	8.07
Overall	89	30	63	63	63	12.38
Contractors without ISO certification *(105 companies)*	**High**	**Low**	**Median**	**Mode**	**Mean**	**SD**
Competition and Business Strategy	26	9	16	16	16	3.31
Role of IT	19	5	10	10	10	2.83
IT Strategy	63	16	32	37	32	8.44
Overall	101	32	58	51	59	13.25

Table 3 contains the results of a check for correlation between number of employees in the company and the sections of questions in the healthcheck survey.

Table 3: Correlation between number of employees of the firm and the IT health check

All Groups *(194 Contractors)*	**Correlation**	**Comment**
Competition and Business Strategy	0.17	No correlation
Role of IT	0.17	No correlation
IT Strategy	0.16	No correlation
Overall	0.18	No correlation

4 Survey of consultant firms

4.1 Sample population

The sample population is taken from the directory of approved consultants kept by the Architectural and Associated-Consultants Selection Board (AACSB) and the Engineering and Associated-Consultants Selection Board (EACSB) of the HKG. Being listed on these directories is not a pre-qualification exercise. It merely means that these companies have expressed an interest in performing government commissions. The two directories are to meet the needs of the AACSB and the EACSB. They are different in style and content.

The AACSB directory contains 96 companies who have registered an interest in providing up to five categories of professional services. There is marked differentiation among these companies with most being registered in a single category. Only 6% of the companies are registered in two categories, and 3% in three categories. All of the companies in the directory are registered as companies in Hong Kong. The attributes of the AACSB information supplied by the Secretary to the AACSB are listed in Table 4. All of the AACSB companies are included in the consultant population sample.

Table 4: Attributes of the population sample supplied by the AACSB

Data attribute	Comment
Code	Unique 6 letter identifier
Company name	
Company address	Hong Kong addresses
Telephone	
Fax	
Companies in each category.	17 No. Building Services Co. 35 No. Architectural Co. 15 No. Quantity Surveying Co. 9 No. Landscaping Co. 32 No. Structural Engineering Co.
Percent of the companies in each category, which are ISO9001, certificated. (77 companies in the population sample (80%) are certificated)	100% Building Services o. 83% Architectural Co. 100% Quantity Surveying Co. 33% Landscaping Co. 75% Structural engineering Co.
No of consultants providing for multiple services	0 No for 5 services 0 No for 4 services 3 No for 3 services 6 No for 2 services
Population sample from AACSB	96 companies

The EACSB directory contains a profile of 347 companies who have registered an interest in providing up to 18 categories of professional service plus a variety of 'other' services. The EACSB directory includes companies registered in Hong Kong and companies operating from overseas. The EACSB directory is more comprehensive than the AACSB. Some of the listed companies provide services that are borderline to the construction process. Works Branch Technical Circular 1/95 (http://www.wb.wpelb.gov.hk/circular/index.htm) explains the use of this directory. It identifies a broad list of consultants for initial consideration for an assignment. Criteria for registration on the directory are not stringent. Culling the EACSB list to remove those companies without a Hong Kong address, or those whose primary business is not construction, results in a population sample of 159 companies. 75% of the population sample register as having expertise in two or more of the categories, 51% are in five or more categories, and 24% are in twelve or more categories. This is evidence that the majority the EACSB consultants are multi-discipline practices. Their response to the questionnaire will reflect the broad nature of their multi-discipline practices and not the special procedures needed for specific professional services. For these reasons the 18 categories of EACSB consultants are placed in the one, multi-discipline category of civil engineering named 'civil'.

The two populations are combined to form the Consultant Population Sample described in Table 5.

Table 5: Data items within the Consultants Population sample

File	Field data	Field attribute
Consultant_pop_sample	CONTRACTOR_REF	Company unique reference code
207 records	COMPANY	Name of company
	NAME	Contact person
	CONTRACTOR_ADS	Contractor's address in Hong Kong
	CONTRACTOR_PHONE	Contractor's telephone number
	CONTRACTOR_FAX	Contractor's fax number
	BUILDINGSERVICES	Category of professional service
	STRUCTURAL	Category of professional service
	ARCHITECTURAL	Category of professional service
	LANDSCAPE	Category of professional service
	QUANTITY SURVEY	Category of professional service
	ENGINEERING	Category of professional service
	ISO	Yes if certificated.

The resultant sample size is 207 companies. Table 6 lists their attributes.

Table 6: General attributes of the Consultants Population sample

Attribute of the population sample
❑ Of the 207 Consultants in the population sample, 154 (74%) are taken from the EACSB directory.
❑ Of the of the 154 EACSB Consultants in the population sample, 60 (39%) have ISO 9000 certification.
❑ Of the 96 AACSB Consultants in the population sample, 77 (80%) have ISO 9000 certification.
❑ Of the 207 Consultants in the population sample, 100 (48%) have ISO 9000 certification.

4.2 Postal release of the questionnaire

The questionnaire was mailed to the sample population on February 27, 1998 so as to arrive on March 2, 1998. The process followed the rules used for the contractor postal survey.

4.3 Results from the Hong Kong consultant firms

By May 8, 1998, 147 questionnaire responses were received. Incomplete responses to the health check survey reduced this to 126 (61%) for analysis. Analysis is the same as the Contractor survey described in Section 3.3. Statistics are listed in Table 7 to show the results overall and for the four population sectors that have a response of at least 15 firms. Also shown are the results for companies with ISO9000 certification and those without certification.

Table 7: Statistical results by population sector of the Hong Kong consultant firms

All *(126 firms)*	**High**	**Low**	**Median**	**Mode**	**Mean**	**SD**
Competition and Business Strategy	26	13	20	19	20.4	3.3
Role of IT	20	5	13	12	13.2	3.2
IT Strategy	62	22	41	41	40.6	9.2
Overall	106	43	74	70	74.1	14.4
Architectural sector *(25 firms)*	**High**	**Low**	**Median**	**Mode**	**Mean**	**SD**
Competition and Business Strategy	26	14	19	19	19.3	3.5
Role of IT	20	5	13	13	12.8	3.8
IT Strategy	56	22	37	37	36.4	9.1
Overall	102	45	68	86	68.6	14.7
Civil sector *(83 firms)*	**High**	**Low**	**Median**	**Mode**	**Mean**	**SD**
Competition and Business Strategy	26	14	21	20	21	3.1
Role of IT	19	6	14	12	13.7	2.9
IT Strategy	62	25	42	41	42.6	8.5
Overall	106	47	77	89	77.3	13.2
Structural sector *(24 firms)*	**High**	**Low**	**Median**	**Mode**	**Mean**	**SD**
Competition and Business Strategy	26	14	20.5	20	20.7	3.7
Role of IT	20	5	13	17	12.7	3.9
IT Strategy	56	22	43	56	41.4	10.4
Overall	102	45	77.5	76	74.8	16.8
QS *(15 firms)*	**High**	**Low**	**Median**	**Mode**	**Mean**	**SD**
Competition and Business Strategy	23	13	19	19	18.8	3.0
Role of IT	16	5	11	10	11.13	3.4
IT Strategy	56	22	30	-	37.3	10.2
Overall	95	43	70	70	67.3	15.4
Consultants with ISO certification *(81 firms)*	**High**	**Low**	**Median**	**Mode**	**Mean**	**SD**
Competition and Business Strategy	26	13	20	19	20.4	3.3
Role of IT	20	5	13	12	13.0	3.5
IT Strategy	62	22	41	41	40.6	9.7
Overall	106	43	61	61	74.0	15.1
Consultants w/o ISO certification *(45 firms)*	**High**	**Low**	**Median**	**Mode**	**Mean**	**SD**
Competition and Business Strategy	26	14	20	22	20.4	3.4
Role of IT	18	8	13	12	13.6	2.7
IT Strategy	56	22	41	41	40.5	8.4
Overall	97	46	74	86	74.3	13.3

Table 8 contains the results of a check for correlation between the number of employees in the company and the sections of questions in the healthcheck survey.

Table 8: Correlation between the number of employees of the firm and the IT health check

All Groups *(126 Consultants)*	**Correlation**	**Comment**
Competition and Business Strategy	0.24	No correlation
Role of IT	0.12	No correlation
IT Strategy	0.17	No correlation
Overall	0.19	No correlation

5 Conclusions

A side-by-side comparison of the overall results in terms of grading is in Table 9. To introduce more sensitivity into the differences a +ve or –ve suffix, or mid-point grading is added to better indicate intermediate positions. The question-by-question strengths and weaknesses of the overall results from the contractors vis a vis the consultant firms is shown in Table 10.

Table 9: Comparison of the surveys carried out in Hong Kong in terms of qualitative grading

Hong Kong Survey	High	Low	Median	Mode	Mean	SD
Survey of 194 contractors	A+	C-	B-	B-	B-	13.08
Survey of 126 consultant firms	A+	C	B+	B	B+	14.4

Table 10: Question-by-question graded performance of Hong Kong contractors (ß) and consultant firms (Ø)

Question	IT unconcerned D	IT Aware C	IT active B	IT innovative A
IT support of core competencies.			ß Ø	
How IT helps company compete.			ß Ø	
Impact of IT on goals and objectives			ß Ø	
Position of IT compared to others.			ß Ø	
Impact of IT on Clients.			ß	Ø
Belief that IT expertise wins work.			ß Ø	
Use of IT as part of strategic alliances.		Ø	ß	
Current use of IT in the company.			ß Ø	
Relationship between IT and business strategy			ß Ø	
Participation of IT in forming business strategy		ß Ø		
Impact of IT on operational strategy.			ß Ø	
IT influence on marketing strategy		ß Ø		
Use of IT systems in company		ß Ø		
Objectives of IT strategy.		ß Ø		
Thrust of IT strategy			ß Ø	
Management of IT in the future		Ø	ß	
CSF's for competitive advantage through IT		Ø	ß	
Management of IT projects and innovation.			ß Ø	
Level of R&D in IT		ß Ø		
Nature of IT department.	Ø	ß		
Importance of IT skills in company.		ß Ø		
Awareness of IT strategy.		Ø	ß	
Involvement of Users in IT strategy.		Ø	ß	
Risks associated with IT strategy.		ß Ø		
Periodic review of IT strategy.			ß	Ø
Measurement of IT performance.			ß Ø	
Characteristics of IT strategy.			ß	Ø
Who champions IT in the company?			ß	Ø

The median, mode, and the mean statistics show a higher degree of IT activity by the consultant firms than the contractors. Those contractors who have a quality assurance certification are more active then those without certification. The opposite occurs among the consultant firms.

The results overall also indicate that the Group C Hong Kong contractors, who are approved for public works projects in excess of HKD $50 million, perform moderately better in the assessment than Group B and Group A. The comparison of results for the population-sectors in the population-sample of consultant firms place the civil engineering sector as the most IT active in terms of highest mode and mean values. Structural engineers are second in terms of highest mean and are highest in terms of median value. Architecture is ranked third and the Quantity Surveyor sector is fourth.

In terms of each of the 28 questions, the Hong Kong contractors were assessed to be 'IT active' in 71% of the questions, and 'IT aware' in the remaining 29% of the questions. The consultant firms were assessed as 'IT innovative' in 14% of the questions; 39% 'IT active', 43% 'IT aware'; and 4% 'IT unconcerned.

In general, the assessment is that the Hong Kong contractors are 'IT active' in most aspects other than including IT in the formulation and delivery of the business strategy and in the marketing strategy. They are 'IT aware' of the use and thrust of the IT and that it is aligned with the goals and objectives of the company; the need for R&D, IT staffing, expertise and skills. Possibly for these reasons, the risks associated with IT are perceived as financial, or technical, and not business or strategic risks.

In comparison, the general assessment is that IT use by the Hong Kong consultant firms is more varied. They are 'IT innovative' with regard to: the impact of IT on clients; periodic review of strategy; characteristics of IT strategy; and champions of IT strategy. They are 'IT active' or 'IT aware' for the majority of the questions but 'IT unconcerned' on the nature of the IT department. The risks associated with IT are perceived as financial, or technical, and not business or strategic risks.

The qualitative evidence gained indicates that the extent of the strategic use of IT by the Hong Kong contractors and by the consultant firms is they are 'IT aware' and 'IT active' but not 'IT innovative' at this time.

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222 GENERIC IT TRAINING: A PROCESS PROTOCOL MODEL

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Abstract

Construction companies have to strategically structure and focus their Business Strategy (BS) in order to maximise benefits. This requires detailed knowledge of the operating environment, stakeholders, resource implications and the management of risk. Information Systems (IS) and Information Technology (IT) can perform a crucial role by supporting and underpinning this strategy. A key element of the IT strategy is generic and specific IT training. These requirements must consider many issues, not least, resource implications, organisational culture, infrastructure and disparate training needs. These needs may also encapsulate both group and corporate issues, in addition to individual, operational, managerial and strategic requirements. This research investigates the use of a Process Protocol training model to analyse the key sequential stages (gates) and links needed, to satisfy, or close, the 'performance gap' between the BS, IS Strategy and subsequent IT Training Strategy.

Keywords: Business Strategy, Information Technology Training, Process Protocol

1 Introduction

The fragmented nature of the construction industry (Emmerson, 1962; Banwell 1964; Latham, 1994) has been cited as a primary factor that adversely affects performance and productivity. Many contemporary 'change' initiatives have tried to improve performance by focussing on time, quality or cost elements. However, 84.4% of commonly associated problems in the construction industry are *process* related (Kagioglou et al, 1998), and not product related. Whilst the use of IT in strategic planning require major management initiatives to deliver

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strategic objectives (Rockart et al, 1996), these have undoubtedly assisted managers assess the capability of their current services and helped determine the IT and business maxims needed to either clarify gaps between what exists and what is required, or find if they have achieved a reasonable match between actual and desired capabilities (Broadbent and Weill, 1997). However, cultural boundaries within business departments often cause problems (Taylor-Cummings, 1998; Grindley, 1992; Mockler and Dologite, 1995), and 'gap' analysis requires a whole series of strategies to be formulated and implemented in order to facilitate the appropriate courses of action (Venegas and Alarcón [3]).

It is important to note that manager's decisions affect how the IT strategy is shaped, understood and accepted by the organisation (Mockler and Dologite, 1995), and interaction between process and IT can assist in the strategic planning process (Hinks et al, 1997). Design strategies for implementing IT solutions into the workplace must therefore include the adoption of new management strategies in order to be successful (Korac-Boisvert and Kouzmin, 1995). Whilst there is a need for mangers to align their IT strategy to the company's IS strategy; more fundamentally, it is equally important to ensure that the IT training strategy is aligned to the IT strategy and BS. This research demonstrates the use and application of Process Protocol applied to a generic IT training model, and assesses its contribution to performance gap analysis.

2 The business strategy and IT training strategy

Construction companies are increasingly aware of the importance of linking their IT support infrastructure to the BS. However, Goulding and Alshawi (1997), noted that whilst construction executives have an exceptional knowledge of their BS, they did not have sufficient knowledge of IT, its capabilities, applications, or association with the IS strategy. Conversely, operational personnel had superficial knowledge of their company's BS, but had a strong knowledge of IS/IT needs and applications. This relationship, indicated in Figure 1, highlights the importance therefore of matching training needs to performance expectations. Construction organisations must therefore critically analyse their BS and investigate whether the current IS support systems are appropriate to meet this strategy contemplating the implications on the IT training strategy.

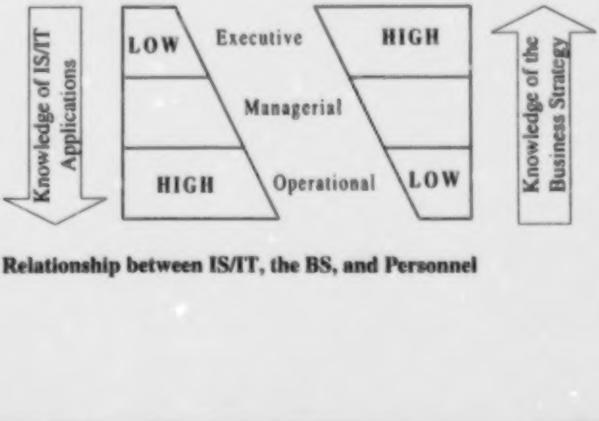
Knowledge of IS/IT Applications
LOW
Executive
HIGH
Managerial
HIGH
Operational
LOW
Knowledge of the Business Strategy

Fig. 1: Relationship between IS/IT, the BS, and Personnel

An organisation's BS should clearly identify the company's key objectives and priorities for a particular timeframe. This strategy is usually governed by numerous factors, and often includes competitor analysis and any immediate challenges facing the company. This strategy should therefore highlight the operational, managerial and strategic needs required to satisfy the BS, the needs of which require the organisation's operatives to have the necessary skills needed to undertake the tasks required. Any deficiencies in skills must be aligned to a suitable training strategy, which is subsequently linked to the BS, indicated in Figure 2.

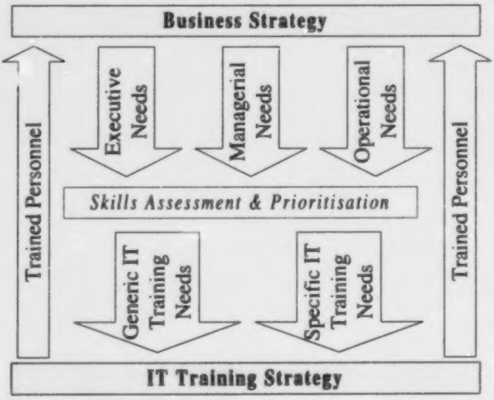

Fig. 2: Relationship of the business strategy to the IT training strategy

Heng (1996), noted that new advances in IT often place demands on personnel, particularly when training is required; but these training and development programmes can often facilitate and provide changes in organisational behaviour, which in turn can enhance the organisation's capability to survive (Kessels and Harrison, 1998). However, whilst IT can help facilitate and deliver the core BS (Moreton and Chester, 1997), employees will require education and training in order to gain new skills for their changed roles (Warszawski, 1996). Training is therefore seen as a key element for improved overall performance (Chang and Cox, 1995), and this management tool is instrumental to addressing skill deficiencies (Krogt and Warmerdam, 1997). Training programmes should however be integrated into the long-term needs of the company, creating enhanced synergies (Kumaraswamy, 1997).

The training strategy within construction organisations should make provision for all generic needs (used by all), and specific needs (used by specialists or group requirements). Feeny and Willcocks (1998) noted that understanding IT capability can deliver core capability, and Mata et al (1995), identified that technical and managerial IT skills were fundamental to delivering any perceived competitive advantage; where technical IT skills are crucial to delivering core activities, and managerial IT skills are essential for exploiting IT and enhancing business performance. Training can improve company performance, but requires formal procedures for measuring its impact on the BS. Feedback on training initiatives can initiate training (or feedback) loops, but no specific mechanism seems to exist which integrates (or evaluates) IT training directly into the BS.

3 Process modelling

Process modelling is a procedure used to analyse complicated structured and unstructured relationships. It is particularly useful for understanding points of view, identifying critical information flows and data relationships. Some of the main process models used are Data Flow Diagrams (DFD); which concentrate on information flows, Integration Definition language 0 for Function Modelling (IDEF-0) and Role Activity Diagrams (RAD); which are popular for modelling problems. The term 'process' can be defined and classified in many ways, especially in the construction and manufacturing industries. However, notwithstanding these differences, the fundamental concepts rely on transforming inputs to outputs, as indicated in Figure 3. Therefore, by using process modelling, many complicated and complex stages can be easily broken down into readily identifiable processes for ease of understanding.

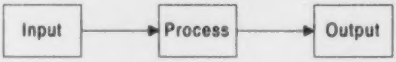

Fig. 3: Components of process

Whilst Shirazi et al (1996), noted the importance of project organisations suitable for associated environments, it is important therefore that construction companies model their business processes before they can automate and improve them. Managers can apply process modelling with some assurance that the actions taken will improve process performance (Soares and Anderson, 1997), and thus, process modelling is a valuable tool for clarifying and understanding processes within organisations.

4 Process protocol

Process Protocol (PP) is a modelling tool capable of representing all diverse parties interested in a process, the flexibility and clarity of which allows generic activities to be represented in framework which encompasses standardisation. This framework encourages users to appreciate process more easily; affording improvements in communication and co-ordination, the control and management of resources, and the adoption of 'shared vision'. Encompassing change management precepts, it allows components of a process to be separated into key phases, based on five key principles, namely, Progressive Design Fixity; Consistent Process; Co-ordination; Stakeholder Involvement/Teamwork; and

Feedback. PP was developed to improve the collaboration between companies in the construction industry, and provide a framework that would improve overall effectiveness. The key attributes and of this framework encompasses the following concepts:

- **Activity Zones**: A structured set of sub-processes designed to support the solution.
- **Deliverables**: Outputs from project and process information, used to create the *Phase Review Report*.
- **Phase Review & Stage Gate Processes**: Generic processes within the stages, separated by decision gates (*Phase Review Meetings*) needed to fix and approve the information prior to progression.
- **Gates & Phase Reviews**: Project and process review points, used to examine progression, dependant upon predefined criteria. Gates are either *Hard* (prevent progression) or *Soft* (accept conditions and allow concurrency).
- **Legacy Archive**: Mechanism for storing, recording and retrieving project and process information.
- **Phase Review Report**: Document of deliverables presented at the phase review gates, the information of which is subsequently stored in the legacy archive.

The generic nature of PP can be applied and adapted to suit many disparate and diverse project environments, and Cooper et al (1998), clearly demonstrates the application of PP to generic design and construction processes. Processes must be managed and controlled in a consistent and predictable manner, and PP offers a framework for improving communication and process management within the construction industry (Kagioglou et al, 1998).

5 Development of a process protocol IT training model

Construction organisations need to make important decisions on deploying finite resources, the rationale of which often balances a range of factors. It was evident however that no real mechanism existed that directly 'measured' the impact of IT training on the BS. A Generic Assessment Process Protocol model for IT training (GAPP-IT) was developed with industry to analyse the key sequential stages (processes) required for instigating and deploying IT training within construction organisations. Two major UK construction companies were used to 'map' IT training issues and processes into a coherent framework for discussion. This framework was subsequently prototyped, tested, and refined, to validate processes and achieve generic taxonomy. GAPP-IT encompasses important decisions needed to be taken to formulate and deploy IT training within a construction environment. Training results, may then be directly measured against the 'performance gap', indicated in Figure 4.

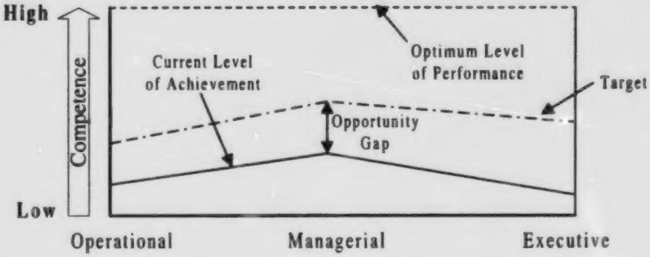

Fig. 4: Performance gap analysis

This research identified three main target groups for analysis, specifically, operational, managerial and executive levels. No attempt is made to discuss the intricacies of resource allocation, corporate culture, or distinguish between organisations that contain subsidiaries or groups. However, the generic nature of this model can encompass these variables. Seven key phases are considered, indicated in Figure 5, which encompass the initial preliminary stages, through to commissioning and feedback. Each of these phases can be collapsed to show lower level information, an example of which can be seen for Phase Zero, indicated in Figure 6. The model is divided into three levels horizontally, covering operational, managerial and executive requirements, and the model is entered at Phase Zero, and exited in Phase Six. A brief summary of each of these phases can be seen as follows:

- **Phase ZERO**: This phase allows users to establish the need for IT training. It evaluates the existing business needs, contemplates the present IS and IT strategy, and assesses all potential resource requirements. The BS is established at this phase, contemplating the prevailing market forces and Stakeholder involvement. If the BS indicates that there is potentially a demand for IT training, users pass through a soft gate into Phase One.
- **Phase ONE**: This identifies the processes involved in formulating a generic IT training strategy. It uses information from Phase Zero, and identifies Critical Success Factors (CSF's) derived from the BS. A skills audit is used to ascertain training needs and levels. If IT training is not required, users exit the model through a decision icon, and the information is stored in the Legacy Archive. Should training be deemed necessary, an outline generic training strategy is formed, and users pass through a soft gate (as no financial commitment has been made) into Phase Two.
- **Phase TWO**: This allocates financial resources to the IT training needs identified in Phase One. The corporate training policy is finalised, and funding is ascertained for generic training needs at operational, managerial and strategic level. Any specific IT training needs deemed not 'generic' at the corporate level, are incorporated at group/subsidiary level, where alternative funding may need to be sought. Training quotations are acquired, and funds are prioritised to the key BS deliverables. A Phase Review board meeting is

required before progression is allowed, as a hard gate (requiring financial commitment) exists.

- **Phase THREE**: This phase establishes the training and control mechanism needed to ensure that any critical needs or deadlines can be met. The CSF's generated by the BS, are agreed, and the type of evaluation and control mechanism is chosen (cognisant of resource implications and appropriateness to the task). This information is then agreed at the Phase Review board meeting, and users subsequently pass through a hard gate into Phase Four.
- **Phase FOUR**: This phase monitors and controls the actual training in accordance with the control mechanism agreed in the preceding phase. A Phase Review board meeting is used to ratify and record progress, and users then pass through a hard gate into Phase Five for evaluation.
- **Phase FIVE**: This phase evaluates the overall training experience from training providers in the form of feedback reports. Training outcomes are measured against the original objectives, and the effectiveness of the control mechanism is evaluated. The existing training policy is updated, and information is stored in the Legacy Archive. A Phase Review report records all this information, and users are then allowed to pass through the final hard gate into the feedback phase (Steering Committee).
- **Phase SIX**: This is the final and most important phase in the GAPP-IT model. It uses a steering committee to overview the whole process of IT training, and evaluates achievements against original objectives. Training is assessed and measured against the performance gap, and open discussion forums are used to foster new ideas and stimulate discussion for new training initiatives. This information is then evaluated in context, noting the company's current deployment of resources, culture, and level of evolvement. The Legacy Archive is used to feed information back into the process management wheel (incorporating any revisions, changes in policy, or change management issues), and the whole process is able to start again.

6 Summary and conclusions

Process models are useful to 'map' ideas and concepts into tangible frameworks for evaluation. Process Protocol takes this one step further by absorbing unprecedented levels of generic detail into its architecture, thereby allowing users to conceptualise and appreciate the links and relationships between processes and sub-processes more readily. The GAPP-IT model allows managers to assess the impact of IT training initiatives on the BS, and decisions can be measured against the performance gap. Furthermore, the corporate skill base can be matched to targets dictated by the BS, and the training strategy's contribution to the delivery of any CSF's can be subsequently evaluated. However, it is important to note that the effectiveness of any training strategy can be influenced by many other factors, not least, stakeholder influence, the prevailing organisational culture and overall management commitment.

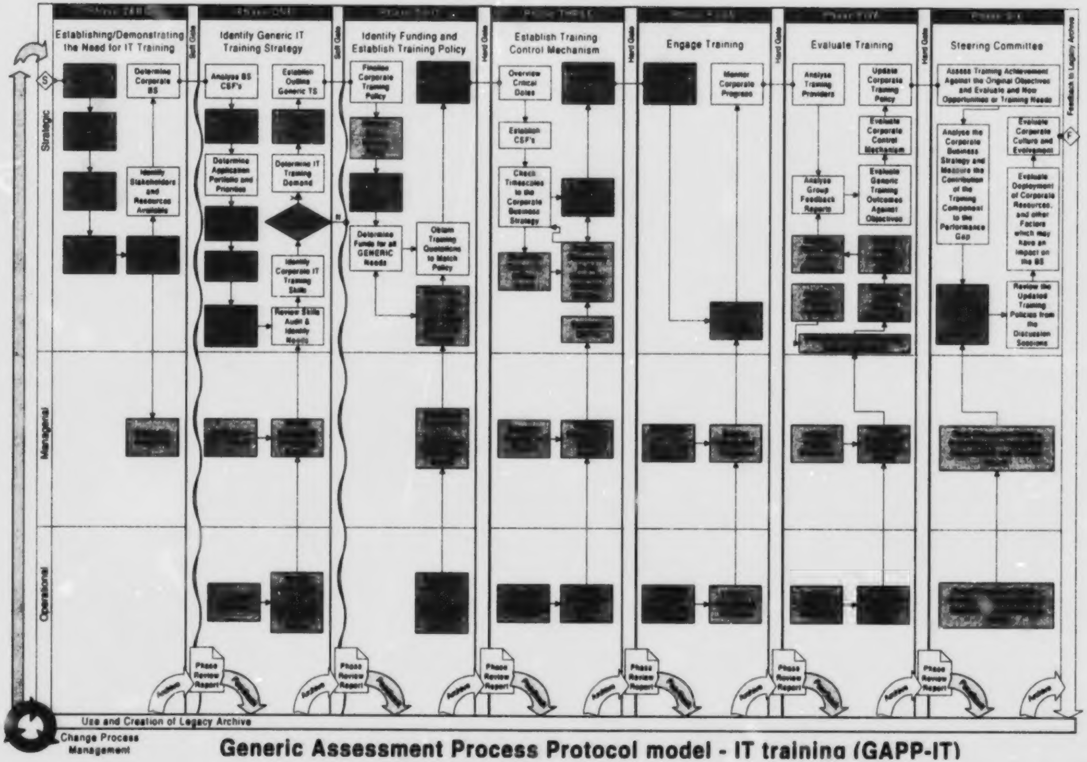
Establishing/Demonstrating the Need for IT Training
Soft Gate
Identify Generic IT Training Strategy
Soft Gate
Identify Funding and Establish Training Policy
Hard Gate
Establish Training Control Mechanism
Hard Gate
Engage Training
Hard Gate
Evaluate Training
Hard Gate
Steering Committee
Feedback to Legacy Archive
S
F
Strategic
Managerial
Operational
Determine Corporate BS
Identify Stakeholders and Resources Available
Analyse BS CSF's
Determine Application Portfolio and Priorities
Establish Outline Generic TS
Determine IT Training Demand
Identify Corporate IT Training Skills
Review Skills Audit & Identify Needs
Finalise Corporate Training Policy
Determine Funds for all GENERIC Needs
Obtain Training Quotations to Match Policy
Overview Critical Dates
Establish CSF's
Check Timescales to the Corporate Business Strategy
Monitor Corporate Progress
Analyse Training Providers
Analyse Group Feedback Reports
Update Corporate Training Policy
Evaluate Corporate Control Mechanism
Evaluate Generic Training Outcomes Against Objectives
Assess Training Achievement Against the Original Objectives and Evaluate and New Opportunities or Training Needs
Analyse the Corporate Business Strategy and Measure the Contribution of the Training Component to the Performance Gap
Evaluate Corporate Culture and Evolvement
Evaluate Deployment of Corporate Resources, and other Factors which may have an impact on the BS
Review the Updated Training Policies from the Discussion Sessions
Phase Review Report
Use and Creation of Legacy Archive
Change Process Management
Generic Assessment Process Protocol model - IT training (GAPP-IT)

Fig. 5. GAPP IT Process protocol model for IT training

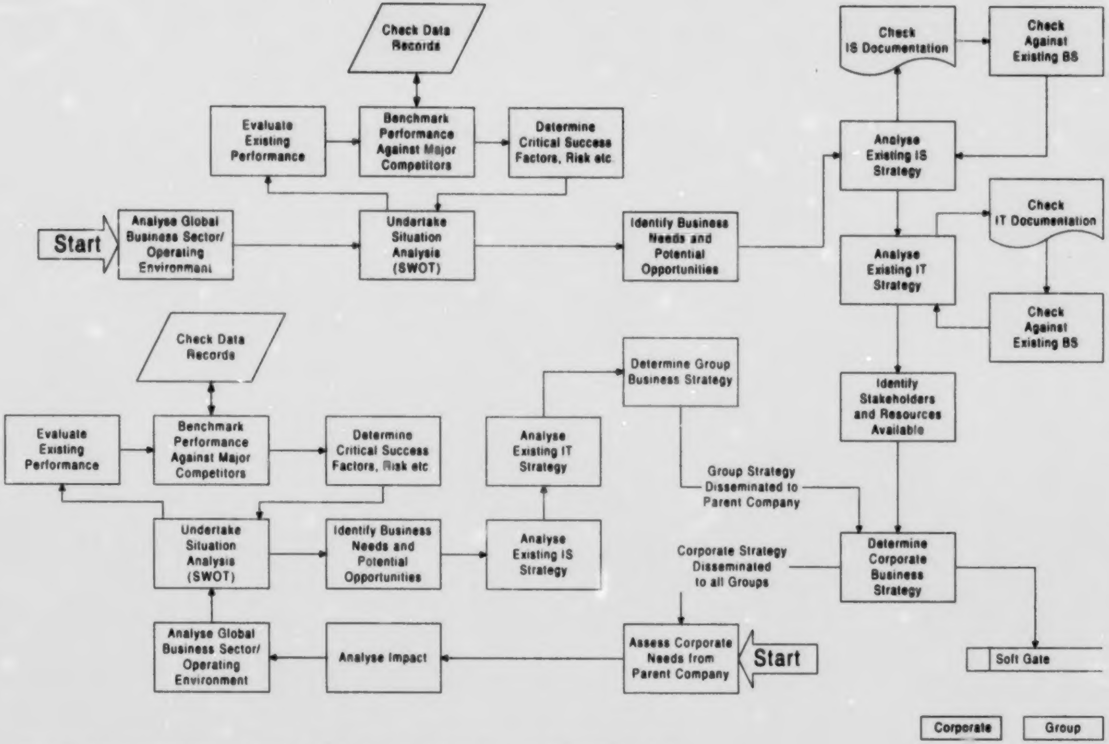
Start
Analyse Global Business Sector/ Operating Environment
Undertake Situation Analysis (SWOT)
Evaluate Existing Performance
Benchmark Performance Against Major Competitors
Check Data Records
Determine Critical Success Factors, Risk etc
Identify Business Needs and Potential Opportunities
Analyse Existing IS Strategy
Check IS Documentation
Check Against Existing BS
Analyse Existing IT Strategy
Check IT Documentation
Check Against Existing BS
Identify Stakeholders and Resources Available
Determine Corporate Business Strategy
Soft Gate
Corporate Strategy Disseminated to all Groups
Start
Assess Corporate Needs from Parent Company
Analyse Impact
Analyse Global Business Sector/ Operating Environment
Undertake Situation Analysis (SWOT)
Evaluate Existing Performance
Benchmark Performance Against Major Competitors
Check Data Records
Determine Critical Success Factors, Risk etc
Identify Business Needs and Potential Opportunities
Analyse Existing IS Strategy
Analyse Existing IT Strategy
Determine Group Business Strategy
Group Strategy Disseminated to Parent Company
Corporate
Group

Fig. 6: Phase ZERO establishing/demonstrating the need for IT training

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223 SURVEY OF INFORMATION TECHNOLOGY AND THE STRUCTURE OF THE SAUDI ARABIAN CONSTRUCTION INDUSTRY

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Abstract

While technical advances are the main drivers in the adoption of Information Technology (IT) in the construction industry, such advances can only be incorporated through a due appreciation of the structures of the industry. Earlier work has shown how the organisational structure of the industry is in large part determined by the nature of the economic and financial exchanges which takes place. New IT initiatives succeed to the degree to which they are congruent with those financial exchanges. In short, economic benefits must accrue. This in turn begs the questions: who benefits, and how are the benefits to be distributed amongst the various parties? The answers to these questions provide the basis for establishing a successful implementation. This short-term 'economic benefits' argument does not, however, preclude a more substantial organisational shift at some later point. In this paper we provide an analysis of the economic structure of the construction industry in Saudi Arabia, and in particular the degree to which IT has established itself in that industrial sector. The Saudi Arabian Construction industry is one of the largest in the world, being devoted to the provision of a large-scale infrastructure. However, in many of its characteristics it is unique. It is these elements of uniqueness which make this particular industry interesting: the uniqueness poses new problems for the developers of novel and innovative IT construction systems. Yet despite these aggregate figures and anecdotal facts the small-scale nature of the construction industry has been poorly researched and documented. The analysis of the economic and organisational structure of the Saudi Arabian IT construction industry provided in this paper provides the fine-grained matrix within which new IT systems can be built. The paper describes an ongoing study of the Saudi Arabian construction industry. It draws together existing facts on the industry and new ones which are being elicited though a large survey of the industry. Finally, it is envisioned that tentative conclusions will be provided on the economic and organisational structure of the industry.

Keywords: Information Technology, Internet, EDI, Construction Industry, Saudi Arabia.

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1 Introduction

The nature of the construction industry is such that virtual enterprises (VEs) are made up of members of the project team working jointly on the design and construction of a facility. A typical project involves the participation of different stakeholders such as the client, architect, structural engineer, building services engineer, quantity surveyor, main contractor, sub-contractor, materials suppliers, and other specialists. Therefore, it can be argued that each project can be considered to be a virtual enterprise and the participating construction companies, which are geographically and functionally distributed, can be considered to be the business units (O'Brien and Al-Biqami 1998).

The application of the virtual enterprise strategy can be seen as a promising approach, since it offers construction firms the opportunity to perform their business without loosing their flexibility and their economic independence within traditional and very rigid co-operations.

The successful application of the virtual enterprise strategy relies on the existence of an appropriate IT infrastructure. This paper focuses on a more specific analysis of the IT infrastructure in Saudi Arabia in a particular industry, the construction industry. We provide an analysis of the economic structure of the construction industry in Saudi Arabia, and in particular the degree to which IT has established itself in that industrial sector. The analysis of the economic and organisational structure of the Saudi Arabian IT construction industry provided in this paper provides the fine-grained matrix within which new IT systems can be built. The paper describes an ongoing study of the Saudi Arabian construction industry. It draws together existing facts on the industry and new ones which are being elicited through a large survey of the industry. Other surveys are ongoing at the time of writing the most interesting being the IT Barometer in Scandinavia (Howard *et al*, 1998).

2 Saudi Arabian construction industry

Saudi Arabia has experienced a construction boom of unprecedented volume during the past two decades, as the country's infrastructure has undergone rapid expansion (including erection of new cities, airports, public and private buildings, highways, etc.) attracting construction professionals from all over the world. The development of the Saudi Arabian construction industry was synonymous with the rapid growth of the domestic economy, which was fuelled by enormous oil revenues. The construction sector is one of the most important contributors to the gross domestic product (GDP) accounting for about 9% of its total value (Ministry of Planning 1991). Companies of all size, involved in this important sector, were established during this rapid growth period.

In Saudi Arabia, the government (Figure 1) is the major source of construction expenditure, accounting for approximately 67% of the nation's construction industry volume (Bubshait 1992). During the second (1975-80), third (1980-85), fourth (1985-90) and fifth (1990-95) Development Plans, the construction industry received 48.7% (SR 295 Billions), 54.9% (SR 674 Billions), 28.2% (SR 231 Billions), and 30.4% (SR 108 Billions) respectively, of the total Governmental expenditure (3.75 SR = 1 US$) (Ministry of Planning 1991).

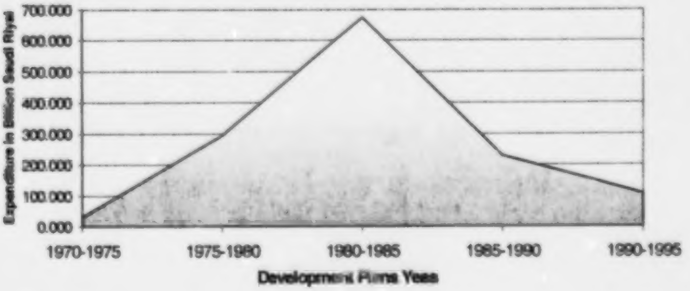

Fig. 1: Governmental actual expenditure on projects during the development plans (from 1970-1995)

A study conducted last year by Riyadh Chambers of Commerce and Industry (Riyadh Chambers of Commerce and Industry 1997) has attempted to estimate the amount of private and public sector projects to be generated in the coming years. The private sector is expected to generate about $50 billion worth of construction projects between 1997 and 2006. The study estimates that the private sector will be responsible for about 70% of new contracts over the next 10 years, which is seen as a considerable increase from the previously estimated contribution of 43%.

The public sector contribution to construction contracts is expected to diminish over the coming years, as its share drops from 57% to 30%. However, the government role will still concentrate on operation and maintenance projects, where it is estimated that the value of new construction projects will be worth about $63.8 billions, of which $24.3 billions will be allocated for operation and maintenance, and $39.5 billions for new projects.

Also the construction industry in Saudi Arabia employs 15% of the total labour force and uses 14% of the total energy consumption in the country (Al-Jarallah 1983).

As can be seen, the Saudi Arabian construction industry is one of the largest in the world, being devoted to the provision of a large-scale infrastructure. However, in many of its characteristics it is unique. It is these elements of uniqueness which make this particular industry interesting: the uniqueness poses new problems for the developers of novel and innovative IT construction tools. Yet despite these aggregate figures and anecdotal facts the small-scale nature of the construction industry has been poorly researched and documented.

3 IT and construction industry in Saudi Arabia

The construction industry in Saudi Arabia has been slow to employ IT. There appear to be no official statistics or comprehensive studies on IT use in the Saudi construction industry. To this point, there has only been a limited survey carried out by Shash and Al-Amir (1997). This survey focussed on the extent of computer use and their applications in construction contractor firms in Saudi Arabia. The findings indicate that computers are not widely used by construction contractors, especially in relation to those who are classified as small and medium-sized contractors. The use of computers is directly proportional to the size of the contractor firm. While, all large contractors use computers, only 41% and 62% of small and medium-sized contractors use them. When computers are used, they are limited to administrative operations such as accounting and databases.

The capability of information technology commonly used by business and the public has changed significantly. Electronic Data Interchange (EDI), the Internet and the World Wide Web (WWW) have had a significant impact and most industries are evaluating how to avail themselves of the opportunities they offer. While, the last survey of large construction firms "Building on IT for Quality Survey" in 1993 conducted by CICA and KPMG (1993) did not even include the Internet, by 1996, a significant number of firms in construction were connected; 25% of UK architects were connected in 1997 with a further 15% intending to open an account (Barbour Index plc 1997).

According to the Barbour Report (1997), about 75% of the industry's professionals have a PC as their workstation, 50% use CD-ROM and 25% have access to the Internet. The report suggests that the take-up of the Internet has doubled form 1996 to 1997 and about 50% of manufacturers have stated that they will publish some or most of their product information on the Internet's World Wide Web.

As indicated above, the feeling is that a good proportion of the Saudi Arabian construction industry is not keeping up with the developments in the use of IT. However, identifying the Saudi construction industry's slowness in adopting IT is only a first step. It is necessary for our study to carry out a comprehensive survey on the use and future development of IT in the Saudi construction industry.

4 Survey description

The survey questionnaire was structured to encourage the relevant organisations to participate in the study; to help them to provide the necessary information easily.

To encourage potential survey participants response, a cover letter was included with each mailed survey. Such letters were signed by both authors. Also, the questionnaires were produced in both English and Arabic languages to suit the needs of the construction community in Saudi Arabia which adopts Arabic as the official language but relies heavily on English as the technical language and the language widely spoken by the dominant expatriate component of construction manpower.

The questionnaires were distributed by post to over 500 organisations within the Saudi Arabian construction industry early in October 1998. The organisations' names and addresses were selected randomly from:

1. The Directory of Engineering and Consulting Offices issued by Engineering Committee, a professional-like association established by the Council of Saudi Chambers of Commerce and Industry in the early 1980s to enhance the engineering profession in the country.
2. The Directory of Classified Contractors prepared by the Contractors Classification Deputy in the Ministry of Public Works and Housing (MPWH).
3. Trade Directory for the Eastern Province prepared by the Chambers of Commerce and Industry for the Eastern Province. This directory includes information concerning 12000 establishments from all sectors, including construction sector, registered as members in the chamber.

The scope of the survey included all participants involved in the industry since the communication technology will eventually tie them all together. Therefore, it was decided that no specific targeting should take place on the basis of organisation type. There is no geographical restriction on the selection of participating organisations – The Kingdom of Saudi Arabia is divided into five regions: East, West, South, North and Central. The survey was sent to top management to assess current use of information and communication technology in their organisation.

The questionnaire established by O'Brien and Al-Soufi (1994) laid the foundation for the development of the study questionnaire. An intensive literature review coupled with comprehensive awareness of the characteristics of the Saudi construction helped to modify and restructure the survey to suit the Saudi construction industry.

The survey was divided into eight sections. The first section contained questions seeking information on the characteristics of the firm, such as size, capacity and type of work performed. The second section contained questions seeking information regarding hardware and software platforms used by the organisation. In the third section, the survey enquired about communication technology that exists within the organisation and asked questions pertaining to the communication between organisations. The fourth and fifth sections asked about the technology used, particularly the Internet and EDI, and the types of data exchanged. The sixth section enquired about computer applications used in the organisation and how they are rated. In section seven, a list of suggestions was offered as to why computer use would be hindered. The last part of the questionnaire was included to encourage respondents to participate in the survey by allowing them to supply their names and address in case they were interested in receiving a copy of the survey results.

5 Characteristics of survey respondents

The response rate to the survey was approximately 10% (46/500). Of responses received, the majority came from building contractors (See Figure 2). The categories of A&E joint practice and manufacturer exhibited as similar response rate at 15.2% and 13%. The remaining categories of consultant, suppliers and engineering all fell below 11%. As far as can be established all the respondents were Saudi Arabian organisations; 12.7% of them engaged in partnerships with overseas firms.

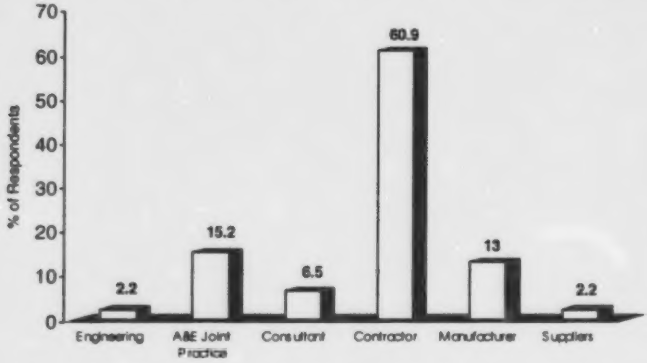

Fig. 2: Type of participating construction organisations

In order to comprehend and analyse the use of information technology in the construction industry in Saudi Arabia, the relevant organisations (See Figure 2) were classified into small, medium and large sizes in relation to their annual turnover.

For the purpose of our study, the construction organisation size is determined according to the following:

1. An organisation is defined as small if its annual turnover is SR20 millions or less.
2. An organisation is defined as medium if its annual turnover is greater than SR20 millions but less than SR50 millions.
3. An organisation is defined as large if its annual turnover is greater than SR50 millions.

This classification is in line with the classification of contractors by the Chambers of Commerce and Industry and the Directory of Construction Contractors in Saudi Arabia. The application of our classification system can be seen in Figure 3. According to our figures, approximately 45% of the participating organisations can be classified as small. Medium-sized organisations accounted for 26.1% while large organisations constitute of 19.6 % (8.7% of respondent were unwilling to provide their annual turnover).

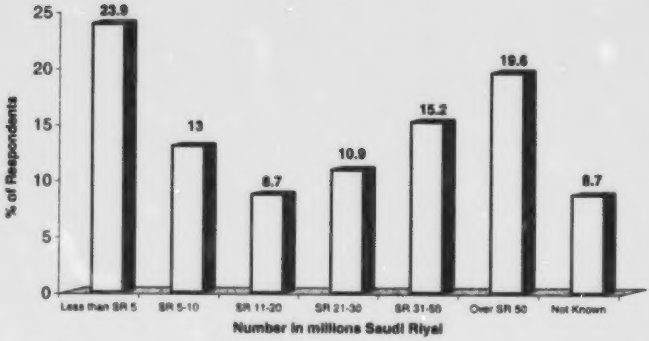

Fig. 3: Construction organisations group distribution

Also the survey attempted to compare the construction organisation's annual turnover with its annual spending on IT. Approximately, 64% of the large organisations and 36.4% of medium organisations spend more than SR100,000 every year, while the small size organisations that have less than SR5 millions annual turnover, spend less than SR1000 every year.

6 Extent of information and communication technology use

The vast majority of respondents to the survey have computers in their organisations. Of construction organisations who do utilise computer, most have PCs (95.7%). A quarter of this figure reported that to have over 50 PCs in their workplaces.

The survey also attempted to determine where computers are located. The physical distribution of computers is a key element in determining the character of internal communication. According to our figures, the vast majority of organisations have their computers located in a main office (93.5%) (See Figure 4). Approximately, 40% also have computers at district offices.

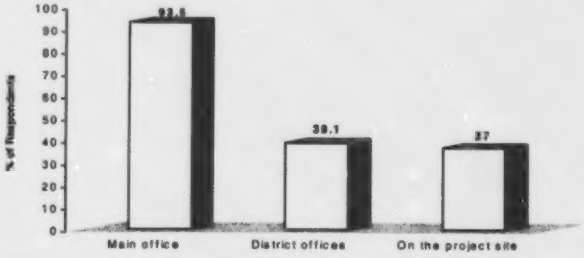

Fig. 4: Computer locations

The most interesting figure, however, is the high-use of computers on-project site (37%). This figure reflects the high computer use of large organisations. 40% of large construction organisations have computers on-project site (See Figure 5). This is most likely due to the ability of large organisations to invest in the computers use based on their high annual turnover.

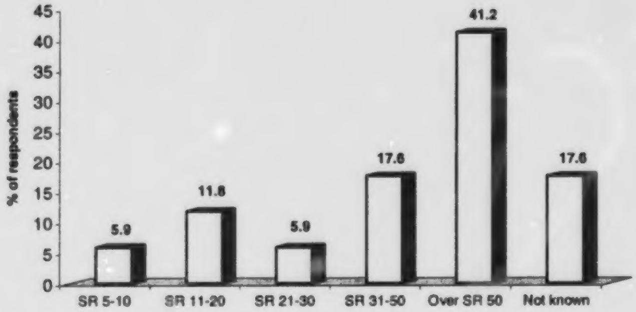

Fig. 5: Computers on-project site and organisations' annual turnover

The survey also examined the level of computer networking *within* the relevant organisations (See Figure 6). The survey revealed that 25% of respondents had all their computers connected together via Local Area Network (LAN), while 22.7% had some LAN infrastructure. Most importantly, 52.3% had no communication infrastructure at all.

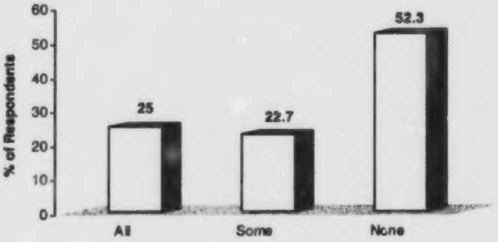

Fig. 6: LAN usage

As for connection between computers in different locations (See Figure 7), 4.8% used Wide Area Network (WAN), while 28.6% utilised modem and telephone lines to exchange data within the same organisation. However, approximately, 67% had no means of communication whatsoever.

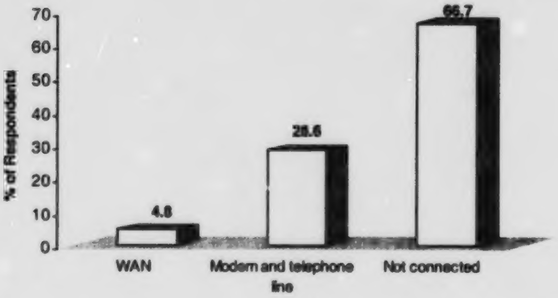

Fig. 7: Inter-organisation communication media

The study also addresses communication *between* different construction organisations (See Figure 8). 76.7% of respondent organisations had no means of connection with other organisations at all (the remaining 23.3% were connected with other organisations).

Of those that were connected, 16.7% used modem and telephone lines, 25% used EDI and 58.3 used alternate methods such as the Internet.

Fig. 8: Communication between different construction organisations

The survey indicates that 28% of organisations have access to the Internet. It is important to note that this access in not provided in Saudi Arabia, but rather comes from surrounding Gulf States (Bahrain, Kuwait, United Arab Emirates, etc.). The majority of respondents that do have access are large organisations. Of the 72% of respondents that do not currently have Internet access, current trends indicate that Internet connection is a priority given the fact that Internet is only now being introduced in Saudi Arabia.

As such, Figure 9 demonstrates that 63.7% of respondents intend to become connected within the next year.

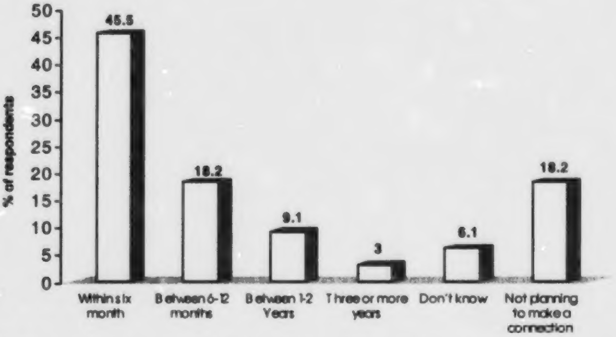

Fig. 9: Construction organisations intend to become connected to the internet

Of the 18.2% that are not planning to make connection, 75% of these state that their business does not require Internet access. The remaining 25% cite lack of expertise as the main reason for not planning to have Internet connection.

Finally, the survey also examined organisation awareness of the EDI. Shockingly, just over 40% of respondents had never heard of EDI technology. In contrast only 8.7% of organisations had implemented it (See Figure 10)

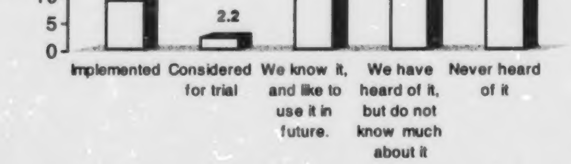

Fig. 10: Construction organisations and EDI awareness

7 Conclusion

This paper has provided a description of the current state of IT and communications in the Saudi Arabian construction industry. The paper first considered the overall and general knowledge that exists, where as the latter part has presented some preliminary results from a survey conducted in October 1998. This survey is probably as current as it can be – questionnaires are still being returned at the time of writing (December, 1998). While the figures have yet to be analysed in detailed, the survey has provided some striking results. Saudi Arabian construction companies are reasonably well advanced with regards to the use of PCs on their construction sites. Yet at the same time the communication structure appears to be poor. The widespread ignorance about EDI does not suggest a bright future for E-Commerce. Yet at the same time the awareness of the Internet suggests exactly the opposite. Indeed, the timing of the survey has been fortuitous. While there is, as yet, no Internet provided within Saudi Arabia – and consequently there is little use – a large proportion of the survey respondents are ready to embrace the technology. But given the relative lack of awareness of EDI it is unclear what use the Internet will be put to. One suspects though this is only a hypothesis, that the "hype" associated with the Internet outweighs the future practical uses, and that companies are embracing it with little thought. Certainly, EDI is more mundane, indeed boring, yet from a business perspective it is of much greater immediate use. A further survey two years from now would make interesting reading.

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224 A SURVEY OF INFORMATION TECHNOLOGY IN THE CANADIAN CONSTRUCTION INDUSTRY

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Abstract

A survey regarding the current and planned use of information technology in the Canadian architecture, engineering and construction industry has been conducted at the end of 1998. The preliminary results of this survey presented here shows the current use of information technology within the firms of the respondents. CAD software has become ubiquitous and is used in most of the drawing work. Even though most firms have adopted e-mail and the Internet, most processes are still not computerized and most documents are still exchanged in a traditional fashion. In general, the adoption of information technology has been beneficial but at a cost. The findings of the survey presented here provide directions in research, development, training, and strategies that will respond to the needs of the industry.

Keywords: Information technology; computers; architecture, engineering, and construction; survey.

1 Introduction

Computers have revolutionized the way documents are generated and information technologies are bound to revolutionize the way people exchange information and documents. These recent technologies have had profound impact on how organizations operate on a daily basis. In order to assess this impact on the architecture, engineering and construction (A.E.C.) industry in Canada a survey was prepared and sent at the end of November 1998. Answers were collected during the months of December 1998 and January 1999.

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Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17743-9

The survey was targeted to executives and managers in the A.E.C. industry. The purpose of this research is to reveal the current and planned use of computer-based and telecommunication technologies in the industry. This paper presents only a preliminary analysis of the answers to the survey as answers are still being collected. The paper commences with a brief overview of the A.E.C. industry in Canada. This is followed by a description of the survey and methodology used. Then the paper presents the profiles of the respondents and the findings of the survey.

2 The Canadian architecture, engineering and construction industry

The Canadian A.E.C. industry employed 933 000 people in 1991 out of a total labour force of 14 475 000 people according to the Canadian census (Statistics Canada 1994). The total value of construction work that was purchased in Canada in 1993 amounted to 94 Billion $Can (Statistics Canada 1993). 65% of this amount corresponds to building constructions while the remaining corresponds to engineering works (e.g., roads, dams, power lines and sewers).

The construction industry is usually considered an important indicator of the health of a national economy. In Canada, the construction output has remained relatively constant in the last 30 years. Since the national gross domestic product (GDP) has steadily grown during this period, the contribution of this industry to the GDP has fallen from 9% to 5% (Statistics Canada 1996). Furthermore, this industry is facing several important challenges such as a steadily decline in productivity since the 60's, high unemployment, a decline in national as well as in foreign markets, little long-term investment, and an "inability to implement crucial competitive policies" (Momaya and Shelby 1998). How does this industry face the added challenge of a paradigm shift in document production and information exchange? This is what the survey presented here tries to answer.

3 Survey's origin and methodology

The questionnaire used in this survey is a slightly modified and improved version (for the Canadian context) of "The IT barometer survey" which was created at the Royal Institute of Technology (Kungl Tekniska Högskolan) of Sweden, in 1997, by Olle Samuelsson (Samuelsson 1998). This survey has since been used in different countries, and thus makes comparison among countries possible. Such results have already been published for Scandinavia in (Howard et al 1998) and (Howard and Samuelsson 1998). The survey is twelve pages long and covers the following topics: company information, computer information, computer use, computer-aided drafting, communications, and information technology.

The survey was sent by mail to executives of a statistical sample of 1000 firms in the A.E.C. industry across Canada. These firms are involved in building construction as well as engineering work. This sample of firms was split in three equal categories: architectural firms, engineering firms, and construction contractors. The only incentive offered to the respondents was to send the findings of the survey.

4 Respondent profiles

The typical return rates for mail surveys in this industry oscillate around 10%. The findings presented here are based on 177 returned questionnaires that represent an 18% return rate. In general, a mail survey cannot be considered reliable under a 50% return rate (Erdos 1983). Even though a low-response was obtained, the findings of the survey still present useful information about the respondents and may show tendencies within the industry. The distribution of responses with respect to the three disciplines surveyed is shown in Figure 1. It seems to be more difficult to interest contractors' executives in filling surveys. The category "Other" consists of manufacturers and distributors. 80% of the respondents were senior management.

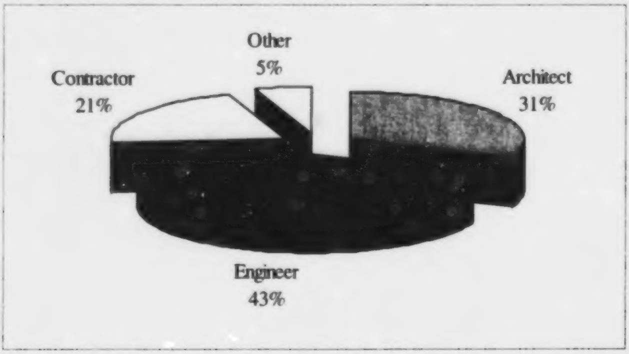

Fig. 1: Distribution of responses for the types of company surveyed

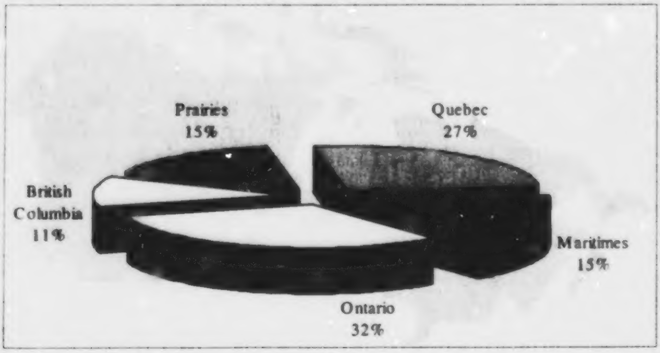

Fig. 2: Distribution of responses within Canada.

The distribution of responses with respect to the five regions of Canada (i.e., British Columbia, the Prairies, Ontario, Quebec and the Maritimes) is shown in Figure 2. This distribution correlates well with the population distribution of Canada except for the Maritimes. The proportion of the responses from the Maritimes is actually twice that of its contribution to the overall population of Canada.

Computers are used by 97% of the firms surveyed. This kind of survey has the deficiency of appealing to people who are already using IT while it rebuffs those who are not. Compared with another survey of technology diffusion in service industries which was conducted by Statistics Canada on behalf of Industry Canada between October and December 1996, at that time, 65% were using personal computers while 5% were either implementing or considering using PCs (Industry Canada 1997).

5 Results

The results of the surveys collected confirm that Microsoft is the dominant brand of operating systems used in the construction industry as shown in Figure 3. Almost 90% of all operating systems installed were sold by Microsoft. The next contender is the Mac OS with a meager 7%.

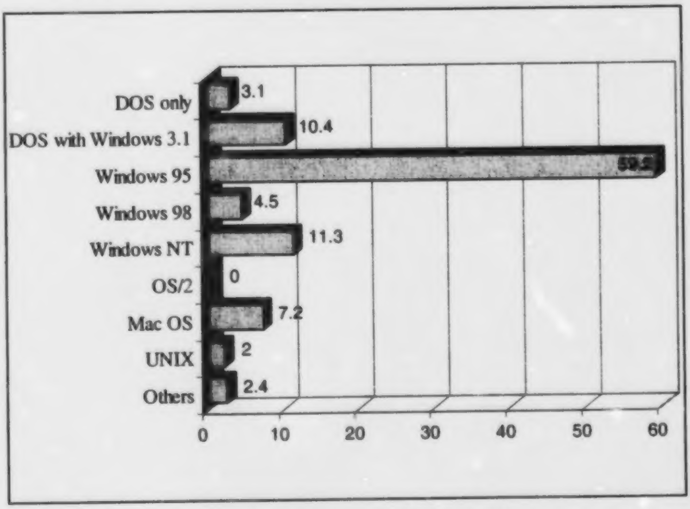

Fig. 3: Distribution of operating systems used in the industry

The survey identified the types of office software used in the industry. Figure 4 shows that almost all firms surveyed use word processors and spreadsheets. E-mail has reached an 84% penetration with an additional 8% implementing it. This is in sharp contrast with the results obtained by Industry Canada in 1996 when only 15% of the A.E.C. firms were using e-mail and 17% were either implementing or considering it (Industry Canada 1997). A similar penetration was achieved with the Internet and the World-Wide Web where now 79% of the firms surveyed are using web browsers while only 15% had access to the Internet in 1996 (Industry Canada 1997). Project planning packages are used only by 43% of the companies surveyed.

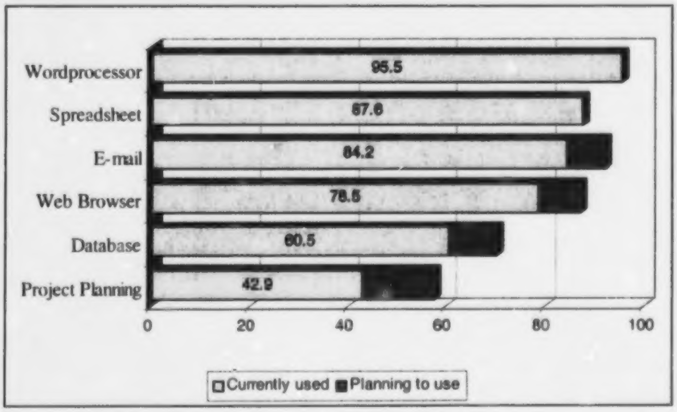

Fig. 4: Types of software used in the industry

The survey evaluated the extent of computerization of some business processes. Figure 5 shows that on one hand invoicing and bookkeeping are largely computerized, while on the other hand, purchasing, tendering, and materials control are mostly manual. The lack of computerization of these processes may indicate a need for efficient software tools in these areas.

An important capability provided by information technology is the transfer of documents in electronic forms. Figure 6 shows that most documents in the industry are not exchanged digitally. Based on these results, design documents are the type of documents with the highest probability (only 25%) to be exchanged often or always in an electronic form. These proportions are bound to augment as more companies are adopting the Internet.

Computer-aided drafting (CAD) is used in 72% of the firms surveyed. As expected, Autodesk is the dominant brand of CAD software used in the industry. Figure 7 shows that 55% of all packages used in the firms surveyed were sold by Autodesk. The next most popular brands are Microstation with 21% and Visio Technical with 14%.

Most of the firms that own CAD packages use them to do the drawing design work. Figure 8 shows that 77 % of these firms use CAD to prepare drawings in 80% to 100% of all drawings. This diagram clearly shows how essential CAD software has become in the industry.

There are several ways to represent drawing information within CAD software. Figure 9 shows that most of the drawings are two-dimensional drawings (i.e., 69% of all drawings). 25% of all drawings integrate databases with two-

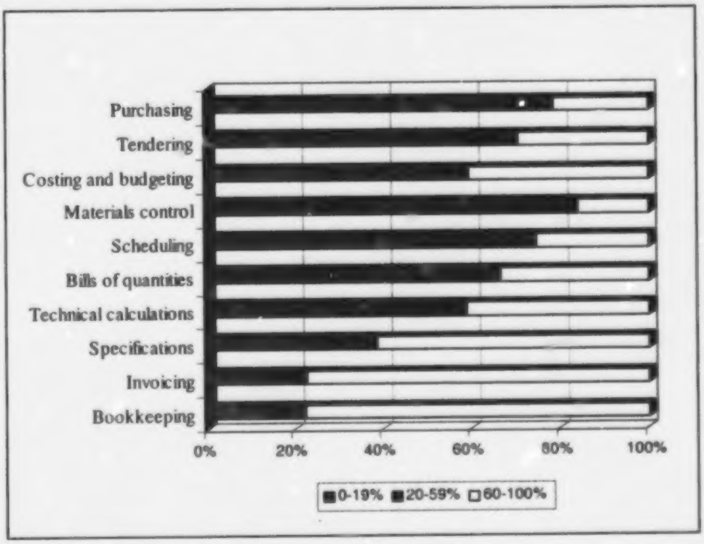

Fig. 5: Extent to which processes are computerized

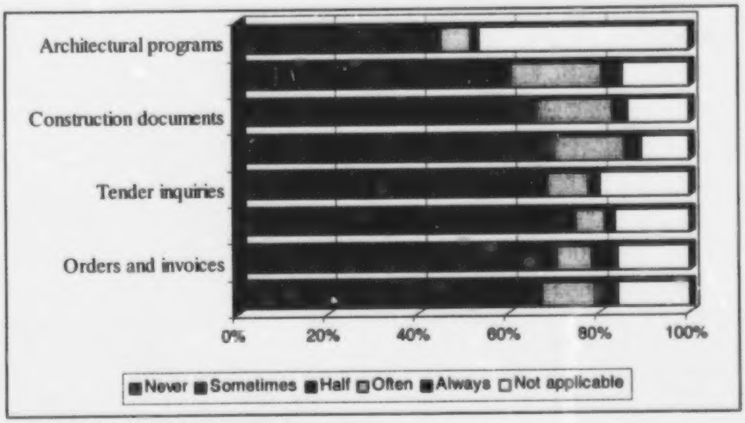

Fig. 6: Digital exchange of information

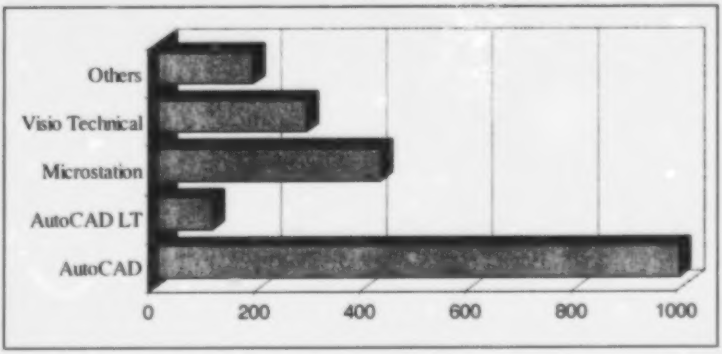

Fig. 7: Number of CAD packages in terms of brand

dimensions. Only 6% of all drawings are done in three-dimensions. Even though product models hold the promise of standardized information exchange and more meaningful design information, its use in Canada in generating drawings is negligible. Canada lags behind Scandinavian countries in the adoption of product models and structured 3D CAD. As a comparison, in Finland, drawings are prepared 13% of the time with product models and 22% of the time with 3D CAD (Howard et al. 1998).

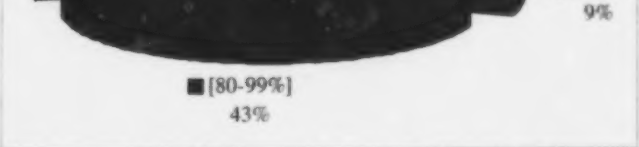

Fig. 8: Estimation of the drawing design work done with CAD

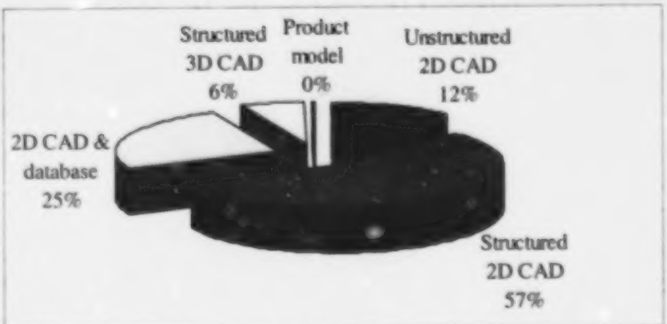

Fig. 9: Percentage of design time with five CAD approaches

One of the objectives of the survey is to find how information technology has changed the design and construction process. According to the results shown in Figure 10, these changes have been both beneficial and detrimental. On one hand, the number of mistakes in documentation has decreased, the number of construction errors has not changed, and the quality of documents and the speed of work have both increased. On the other hand, the complexity of work, the administrative needs, the proportion of new operations and the costs of doing business have all increased. The benefits of information technology come at a cost.

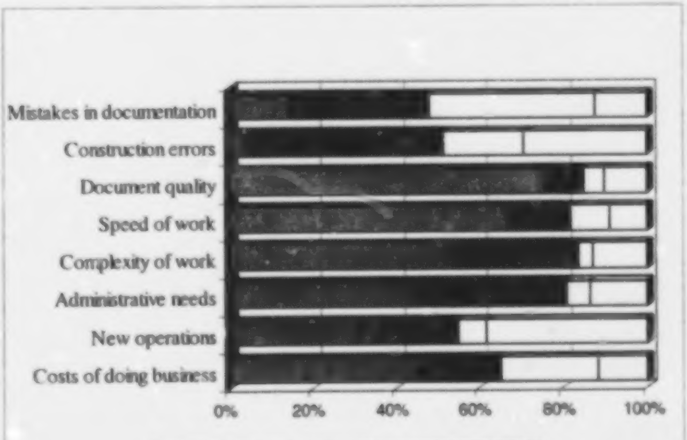

Fig. 10: Changes caused by the introduction of information technologies

The respondents were asked to select the research topics they considered the most important for their firms. Figure 11 shows the set of topics proposed along with their respective score. The results show clearly that the firms surveyed need a way to integrate their operations using computers since the two related topics computer-integrated construction and standard format for the electronic exchange of product data have both scored high. Two other topics that have scored high are concerned with design support. Design tools that would allow concurrent design and support conceptual design would be welcomed. On the other hand, most of the firms surveyed do not see the needs for robot-construction and virtual reality applications.

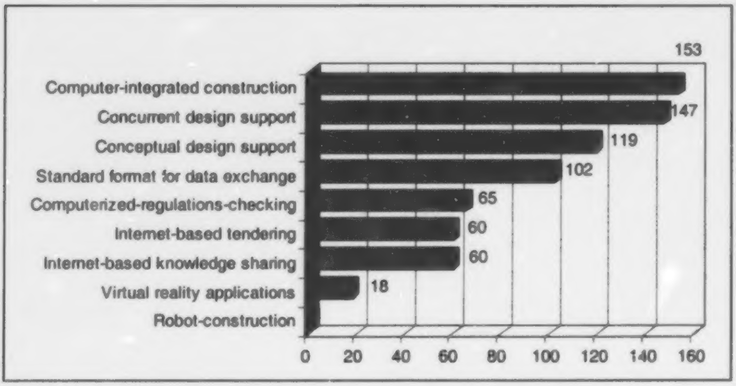

Fig. 11: Research needs identified by the industry

6 Conclusion

The preliminary findings presented here provide a glimpse of the current use of information technology within the Canadian A.E.C. firms that have responded to the survey. Even though most firms have adopted e-mail and the Internet, most processes within these firms are still not computerized and most documents are still exchanged in a traditional fashion. The fact that some data-intensive processes, such as purchasing, tendering, and materials control, are not fully computerized yet may indicate the need for the development of better software tools in these areas. In general, the adoption of information technology has been beneficial but has increased, as a side effect, the complexity of work, the administrative needs and the cost of doing business. If software was simpler to use and more reliable, these side effects would probably vanish. According to the firms surveyed, the most important area of research for the industry is the implementation of computer-integrated design and construction, which integrates data and communication among firms. With such an environment, A.E.C. firms would exchange much more information in digital forms. The next most important area of research is the development of new design tools that would let several designers work concurrently on a project and that would assist them in exploring many alternatives during the conceptual stages of design.

7 Acknowledgements

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225 INTEGRATION OF CONSTRUCTION MANAGEMENT FUNCTIONS

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Abstract

To date, the development of construction management software has focussed primarily on the generation of a project plan and schedule, its monitoring, updating and revision, i.e., it has adopted a process-centric approach. However, there is a growing awareness of the need to support other functions such as productivity analysis, change management and quality management, to name a few. The development of computer-based systems that support a broad spectrum of interdependent functions (interdependent in terms of data and information requirements) leads to the topic of integration and how best to achieve it. Described in this paper is a multiple-view representation of projects that facilitates the integration of and computer assistance for a diverse range of functions. Productivity analysis is used as a context to present the opportunities such a representation offers for integration and an enriched and expanded function set.

Keywords: Integration; management functions; project views; productivity analysis.

1 Introduction

The purpose of this paper is to outline an approach for enhancing and enlarging the software tool kit for construction management personnel. To date, those involved in developing software tools for such personnel have tended to focus on the generation of a project plan and schedule, its monitoring, updating and revision. Consequently, a process-centric approach has been used to represent projects – i.e., the belief is that a project can be described in terms of a set of activities, and all essential information can be associated with these activities in the form of attributes. The reality of construction management functions is that planning and schedule control constitutes only a small part. Consequently, managers have pursued the use

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of spreadsheets, and custom and commercial data base systems to support other functions, including the mining of data to generate insights on project performance or to conduct post project analyses in support of claims or knowledge for use on future jobs. As a result, management does not end up with a coherent representation of the various facets of a project, leading to redundancy in data, errors, and inadequate support for many functions.

We seek to break out of such a narrow process-centric definition for construction management software, and move closer to the range of tasks actually carried out by management personnel during the execution and post-construction phases of a project. We do not include the estimating and cost accounting functions in our scope because practices are ingrained, head or regional office personnel generally perform them, and they invariably involve the use of dedicated systems. However, one has to be concerned how construction management systems can interface with these other systems to facilitate the seamless transfer of information in both directions – i.e., site to office, office to site, and thus support the broadest range of functions possible. The development of computer-based systems that satisfy the desire to support the broad spectrum of interdependent functions (interdependent in terms of data and information requirements) leads to the topic of integration and how best to achieve it. Integration refers to the support within a single system and through connectivity to other systems of a comprehensive set of construction management functions.

As a step toward integration, we have adopted a six-view representation of a project as follows: (1) Physical View – what is to be built and the site context; (2) Process View – how, when, where and by whom; (3) As-Built View – what happened, why and actions taken; (4) Cost View – how much and from whose perspective; (5) Quality View – compliance requirements and achievements for input and output products; and, (5) Change View – what changed, why and consequences for other views. These views are not unique (i.e., other definitions are possible), but they tend to mirror the thought processes of construction personnel and we have found our choice to be useful for supporting new functions and enhancing existing ones.

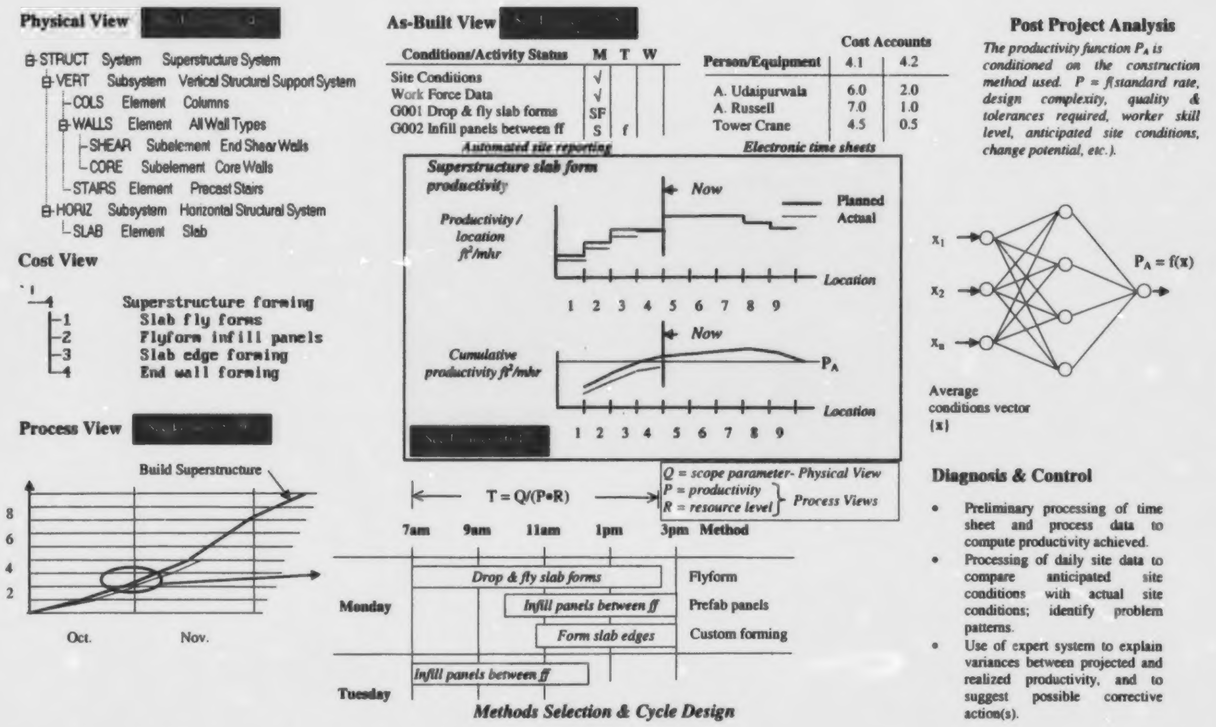
Current work directed at expanding the scope of functions supported through software systems includes the representation, tracking, selection and evaluation of construction methods (Udaipurwala & Russell 1998), intelligent assistance in formulating a schedule based on a physical description of a project (Chevallier & Russell 1998), (Russell 1998), and automated assistance in terms of evaluating the quality of a schedule. All of this work involves the use of the Physical View of a project as well as the Process View. New or complementary functions being pursued include productivity analysis as described in the next section, the detection and diagnosis of site problems which involves four views (Physical, Process, As-built and Cost), and the detection and diagnosis of quality problems (Battikha & Russell 1998).

In the remainder of this paper, we describe selected aspects of a research system that uses a multiple-view representation. (The system is in transition from a DOS world to a Windows one.) By integrating these views, i.e., allowing them to share data, new opportunities can be created to enlarge and enrich the function set that can be supported through software. Within several of the views, use is made of generalized, hierarchical classification structures, as construction projects lend themselves naturally to a hierarchical decomposition. Due to space constraints, attention is directed mainly at the first three views described previously. The topic of productivity analysis is used to focus the discussion, although reference is made from time to time to other functions.

2 Productivity analysis

Fig. 1 provides an overview of the function that we have called productivity analysis. By productivity analysis, we mean developing productivity profiles and comparing them to expectations set out in the estimate (P_A as shown in Fig. 1), establishing benchmarks for control (location and/or time varying profiles of productivity) generating as-built productivity profiles using payroll data and Physical View data, conducting variance analysis to explain differences between as-planned and as-built performance, and generating productivity functions for estimating future jobs. On the left-hand side of Fig. 1, a hierarchical representation of the Physical View of a project is depicted, which is elaborated upon in Figs. 2-4. Data from the Physical View is used as the numerator (output) in the productivity equation, and for input to productivity and duration estimating relationships. The Cost View on the left-hand side is also represented in a hierarchical structure, and relates to the need to connect the Process View with the As-Built View in order to assess capital productivity and compare as-built with as-planned achievements. The lower left-hand side of Fig. 1 depicts the Process View of the project, including a detailed methods statement for purposes of assessing productivity at a number of levels. This aspect of Fig. 1 is elaborated upon in Figs. 5-9. The shaded area in the middle depicts the as-planned and as-built productivity achievements for the superstructure slab form element (similar profiles can be developed for any other component in the Physical View). Generation of these profiles requires input from the Physical, Process, As-Built and Cost Views. A system-generated version of this profile is shown in Fig. 12. The As-Built View on the top of Fig. 1 reflects the gathering of information to document and explain actual performance, and involves an intersection with the Cost View in terms of the collection of payroll data. Aspects of the As-Built view are elaborated upon in Figs. 13-15. The Diagnosis and Control component of Fig. 1 highlights the potential for improved assistance to construction personnel through integration of views and functions and the incorporation of expert knowledge. Lastly, the right hand side of Fig. 1 deals with the processing of project data after project completion in order to provide feedback to the firm's estimating function. We think this approach provides a more holistic view of the productivity analysis problem through the construction phases as opposed to the traditional approach to modeling productivity that concentrates on the planning phase alone (Randolph et al. 1990 and Tavakoli 1985).

Figs. 2-4 depict various aspects of a Physical View or Physical Component Breakdown Structure (PCBS) of a project that we believe are essential to support a range of functions. Fig. 2 shows the hierarchical structure of the Physical View. It involves a simple language dealing with allowable components, and a limited rule set regarding the structure required. Considerable flexibility exists in terms of the level of detail that the user specifies. The formulation of the PCBS can be facilitated through the use of user-defined standards and templates (see Standards, Fig. 13). Components of the PCBS hierarchy can be described in terms of Attributes, Values, Multi-Media Records, and association with Activities, Pay-Items (Cost), Quality and


Physical View
⊟ STRUCT System Superstructure System
⊟ VERT Subsystem Vertical Structural Support System
COLS Element Columns
⊟ WALLS Element All Wall Types
SHEAR Subelement End Shear Walls
CORE Subelement Core Walls
STAIRS Element Precast Stairs
⊟ HORIZ Subsystem Horizontal Structural System
SLAB Element Slab
Cost View
4 Superstructure forming
1 Slab fly forms
2 Flyform infill panels
3 Slab edge forming
4 End wall forming
Process View
Build Superstructure
8
6
4
2
Oct.
Nov.
As-Built View

Conditions/Activity Status	M	T	W
Site Conditions	√		
Work Force Data	√		
G001 Drop & fly slab forms	SF		
G002 Infill panels between ff	S	f	

Automated site reporting

	Cost Accounts	
Person/Equipment	4.1	4.2
A. Udaipurwala	6.0	2.0
A. Russell	7.0	1.0
Tower Crane	4.5	0.5

Electronic time sheets

Superstructure slab form productivity
Now
Planned
Actual
Productivity / location ft²/mhr
Location
1 2 3 4 5 6 7 8 9
Now
Cumulative productivity ft²/mhr
P_A
Location
1 2 3 4 5 6 7 8 9

$T = Q/(P \bullet R)$

Q = scope parameter- Physical View

P = productivity, *R = resource level* } *Process Views*

Methods Selection & Cycle Design

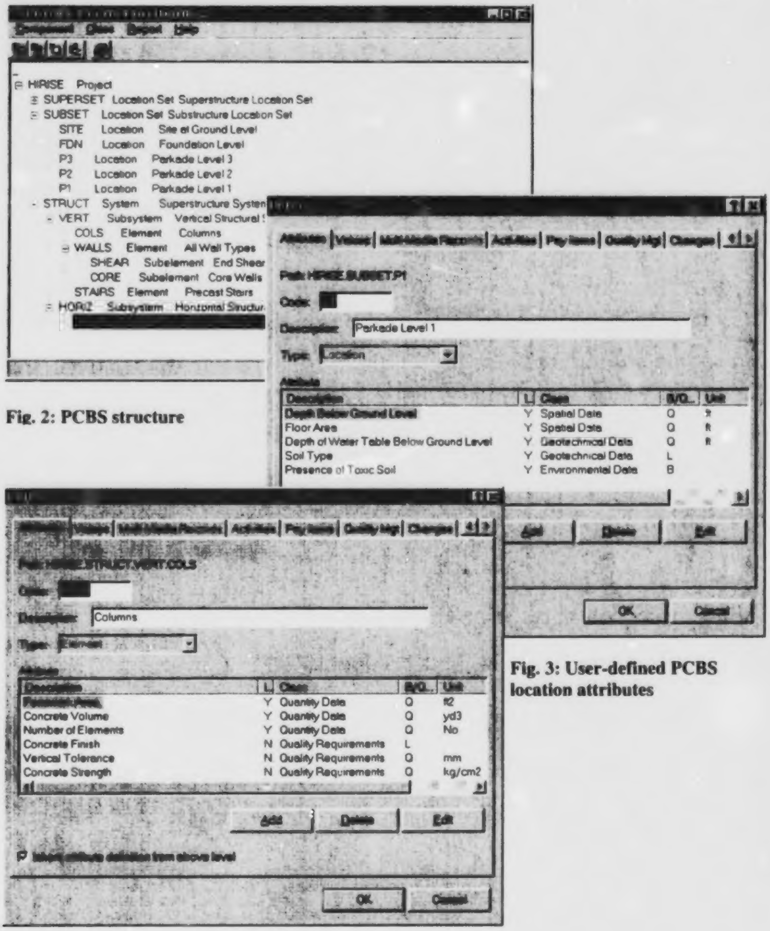
Post Project Analysis

The productivity function P_A is conditioned on the construction method used. P = f(standard rate, design complexity, quality & tolerances required, worker skill level, anticipated site conditions, change potential, etc.).

Diagnosis & Control

- Preliminary processing of time sheet and process data to compute productivity achieved.
- Processing of daily site data to compare anticipated site conditions with actual site conditions; identify problem patterns.
- Use of expert system to explain variances between projected and realized productivity, and to suggest possible corrective action(s).

Fig. 1: Productivity analysis and its relationship to various project views



```
⊟ HIRISE   Project
  ⊞ SUPERSET  Location Set  Superstructure Location Set
  ⊟ SUBSET   Location Set  Substructure Location Set
      SITE    Location    Site at Ground Level
      FDN     Location    Foundation Level
      P3     Location    Parkade Level 3
      P2     Location    Parkade Level 2
      P1     Location    Parkade Level 1
  - STRUCT   System     Superstructure System
    - VERT    Subsystem   Vertical Structural S
       COLS    Element    Columns
      ⊟ WALLS   Element    All Wall Types
         SHEAR   Subelement  End Shear
         CORE    Subelement  Core Walls
       STAIRS   Element    Precast Stairs
    ⊞ HORIZ   Subsystem   Horizontal Structur
```

Fig. 2: PCBS structure

Attributes | Values | Multi-Media Records | Activities | Pay Items | Quality Mgt | Changes
Add
Delete
Edit
OK
Cancel

Path: HIRISE.SUBSET.P1

Code:

Description: Parkade Level 1

Type: Location

Attributes

Description	L	Class	B/Q..	Unit
Depth Below Ground Level	Y	Spatial Data	Q	ft
Floor Area	Y	Spatial Data	Q	ft
Depth of Water Table Below Ground Level	Y	Geotechnical Data	Q	ft
Soil Type	Y	Geotechnical Data	L	
Presence of Toxic Soil	Y	Environmental Data	B	

Fig. 3: User-defined PCBS location attributes

Path: HIRISE.STRUCT.VERT.COLS

Code:

Description: Columns

Type: Element

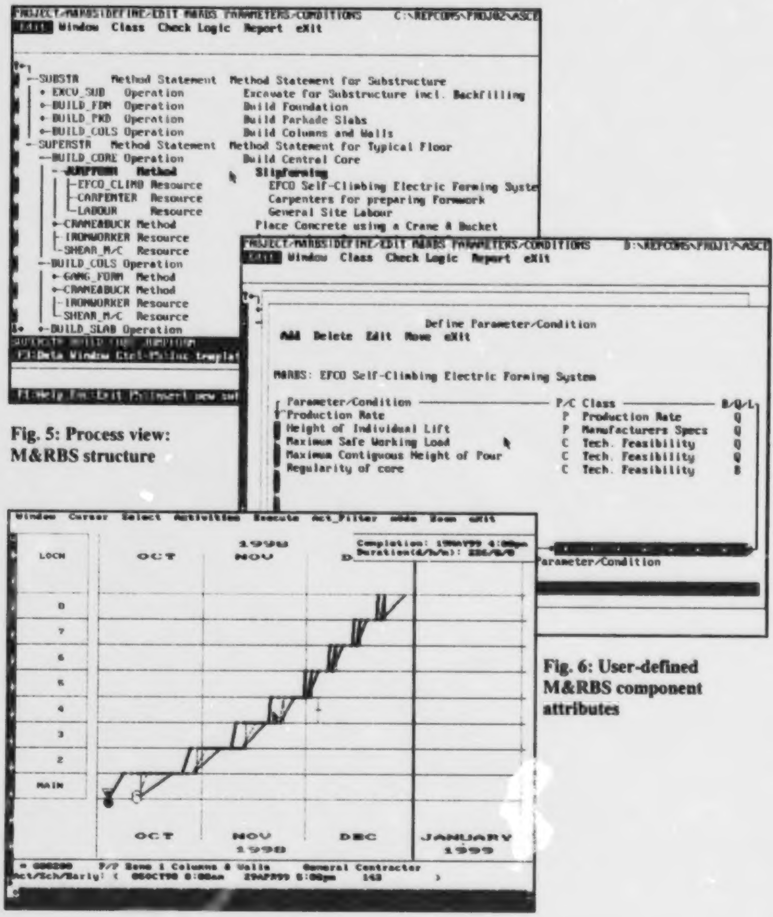
Attributes

Description	L	Class	B/Q..	Unit
[illegible]	Y	Quantity Data	Q	ft2
Concrete Volume	Y	Quantity Data	Q	yd3
Number of Elements	Y	Quantity Data	Q	No
Concrete Finish	N	Quality Requirements	L	
Vertical Tolerance	N	Quality Requirements	Q	mm
Concrete Strength	N	Quality Requirements	Q	kg/cm2

☑ Inherit attribute definition from above level

Fig. 4: User-defined PCBS element attributes

Change Views. Figs. 3 and 4 show the user specification of attributes for a spatial element (Location) (Parkade Level 1), and a physical Element (Columns). Note that inheritance is supported. The concept of locations shown in Fig. 2 is central to the Physical View, as it allows one to carry out functions/reasoning that depends on the project's spatial context and anticipated site conditions (e.g., checking for congestion, assessing the feasibility of a construction method). Attributes can be Quantitative, Boolean or Linguistic, and further can be grouped into user-defined classes to facilitate various functions (e.g., duration estimation, quality management).



```
PROJECT/M&RBS|DEFINE/EDIT M&RBS PARAMETERS/CONDITIONS      C:\REPCON5\PROJ02\ASCE
EDIT  Window  Class  Check Logic  Report  eXit

 --SUBSTR     Method Statement  Method Statement for Substructure
  • EXCU_SUB   Operation           Excavate for Substructure incl. Backfilling
  •-BUILD_FDN  Operation           Build Foundation
  • BUILD_PKD  Operation           Build Parkade Slabs
  •-BUILD_COLS Operation           Build Columns and Walls
 --SUPERSTR   Method Statement  Method Statement for Typical Floor
   --BUILD_CORE Operation          Build Central Core
     --JUMPFORM   Method             Slipforming
       |-EFCO_CLIMB Resource            EFCO Self-Climbing Electric Forming Syste
       |-CARPENTER  Resource            Carpenters for preparing Formwork
       |-LABOUR     Resource            General Site Labour
     •-CRANE&BUCK Method             Place Concrete using a Crane & Bucket
     |-IRONWORKER Resource
     |-SHEAR_M/C  Resource
   --BUILD_COLS Operation
     •-GANG_FORM  Method
     •-CRANE&BUCK Method
     |-IRONWORKER Resource
     |-SHEAR_M/C  Resource
   •-BUILD_SLAB Operation
```

Fig. 5: Process view: M&RBS structure

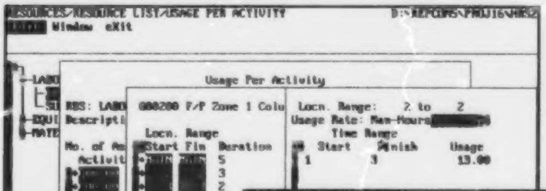
```
PROJECT/M&RBS|DEFINE/EDIT M&RBS PARAMETERS/CONDITIONS      D:\REPCON5\PROJ17\ASCE
EDIT  Window  Class  Check Logic  Report  eXit

                    Define Parameter/Condition
 Add  Delete  Edit  Move  eXit

 M&RBS: EFCO Self-Climbing Electric Forming System

 Parameter/Condition ------------------------ P/C Class ---------------- B/Q/L
 Production Rate                               P  Production Rate          Q
 Height of Individual Lift                     P  Manufacturers Specs      Q
 Maximum Safe Working Load                     C  Tech. Feasibility        Q
 Maximum Contiguous Height of Pour             C  Tech. Feasibility        Q
 Regularity of core                            C  Tech. Feasibility        B

 Parameter/Condition
```

Fig. 6: User-defined M&RBS component attributes

Fig. 7: Process view: linear planning chart

The description of any member of the hierarchy in terms of its associations with other views is key to the goal of integration. This is an area of research focus at the present time as current industry practice does not preclude very different levels of detail in terms of Process, Cost and As-Built representations of a project. Imposing the constraint of one to one mappings is far too simplistic.

Fig. 5 depicts a hierarchical methods & resource breakdown structure (M&RBS), in support of the Process View. The user is able to formulate, using a simple language (method statement, operation, method, resource, fragnet), detailed method statements. Similar to the PCBS structure, the user is allowed to associate different



Window eXit

Usage Per Activity

Locn. Range: 2 to 2

Usage Rate: Man-Hours

Locn. Range

Start Fin Duration

5
3
2
1
1
1
2
2

Time Range

Start Finish Usage

1 3 13.00

Fig. 8: Resource loading a schedule

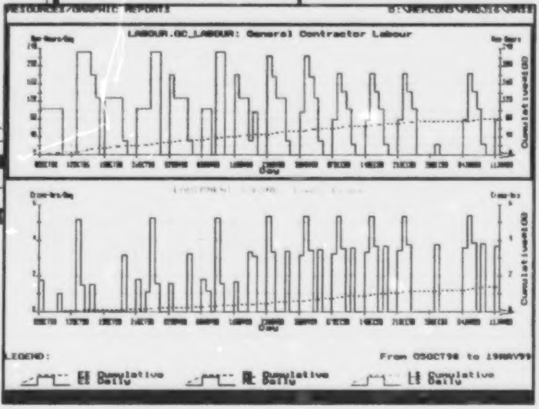
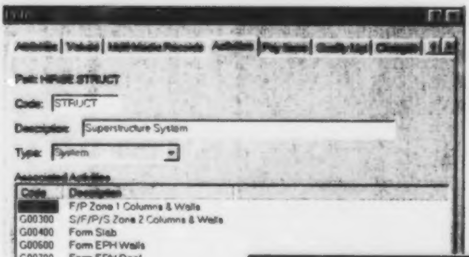


Fig. 9: Resource usage histogram

kinds of information with each component in the M&RBS. For example, Fig. 6 shows a set of user-specified parameters and conditions that relate both to a project's physical context and production capabilities of the technology at hand. This information can be used for assessing the suitability of a method for a project and for estimating activity durations. Association with a Physical View is essential for both.

Once a set of activities are defined, sequenced and a duration estimated for each (Process View), all of which are a function of the physical properties and site context of a project and methods selected, the project schedule can be computed. A project plan in the form of a linear planning chart is shown in Fig. 7. If one attaches additional attributes to activities in terms of a resource assignment (Fig. 8), then resource usage histograms can be generated both for time (Fig. 9), and for space (not shown). For the latter, the existence of a Physical View will then allow additional analysis to be performed, such as checking for congestion at peak work times at various work locations (knowing spatial attribute values such as area per work location and resource usage at a given location and point in time, the potential for crowding can be assessed, and hence the quality of the schedule can be evaluated).

Figs. 10-12 show a value-added function in the form of productivity analysis for the planning phase. Fig. 10 shows the association of activities with a component of the PCBS. Fig. 11 shows the user selection of activities to be examined (the activities associated with the physical component of interest), the physical component (slab) and its attribute (formwork area) of interest, and the resource (general contractor labour) of interest (resources can also be described in terms of a hierarchy). The



Path: HIRISE STRUCT

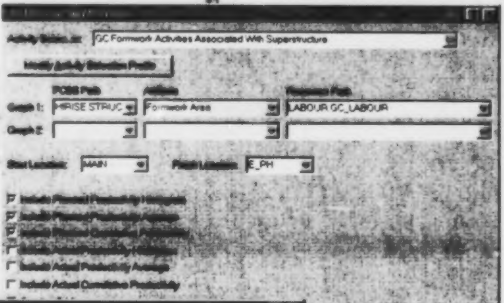
Code: STRUCT

Description: Superstructure System

Type: System

Code	Description
[illegible]	F/P Zone 1 Columns & Walls
G00300	S/F/P/S Zone 2 Columns & Walls
G00400	Form Slab
G00600	Form EPH Walls
G00700	Form EPH Roof
G00900	Strip EPH Walls

Fig. 10: Association of activities and PCBS component



GC Formwork Activites Associated With Superstructure

	PCBS Path		
Graph 1:	HIRISE STRUC	Formwork Area	LABOUR GC_LABOUR
Graph 2:			

MAIN

E_PH

Fig. 11: Specifying productivity analysis profile parameters

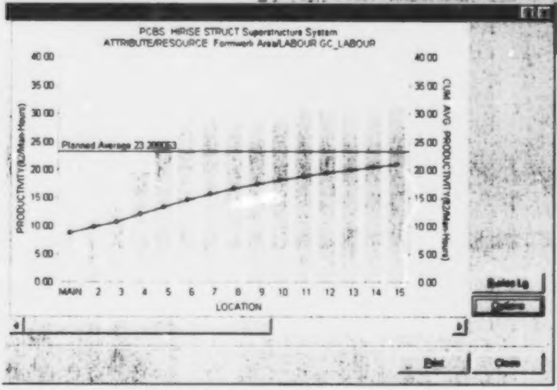


Fig. 12: Productivity analyisis profile

system then extracts the relevant data from the Physical and Process Views to generate the productivity profile sought. The average productivity over all locations can also be computed, and it can be used to check consistency with the original estimate, which is generally based on an estimate of average productivity. Such a consistency check is very important, and is often not done. An additional benefit from generating the productivity profile is that it can be used as a benchmark for control. Later on, when payroll data is collected from the field (the Cost View), actual productivity profiles can be generated, although that may have to be done for

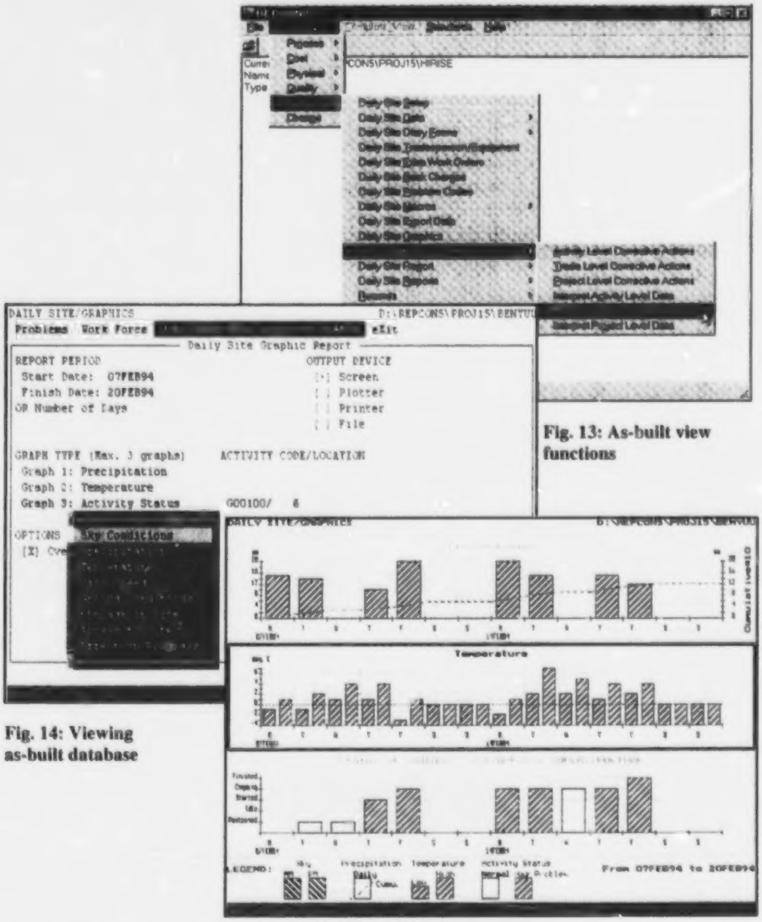


Fig. 13: As-built view functions

```
DAILY SITE/GRAPHICS                                D:\REPCONS\PROJ15\BENTU
                  Daily Site Graphic Report
REPORT PERIOD                          OUTPUT DEVICE
 Start Date:  07FEB94                  [•] Screen
 Finish Date: 20FEB94                  [ ] Plotter
OR Number of Days                      [ ] Printer
                                       [ ] File

GRAPH TYPE (Max. 3 graphs)     ACTIVITY CODE/LOCATION
 Graph 1: Precipitation
 Graph 2: Temperature
 Graph 3: Activity Status       G00100/   6

OPTIONS
 [X] Ove
```

Fig. 14: Viewing as-built database

Fig. 15: Searching for cause-effect relationships

more aggregated components in the physical hierarchy as field personnel may not code data at the same level of detail found in the estimate or project.

Fig. 13 shows the ingredients of the As-Built View. Data collected in this view is essential for comparing actual performance against planned performance, and for explaining reasons for schedule, cost and productivity variances. A tie in exists between the As-Built View and the Cost View in the form of the Daily Site Tradesperson/Equipment data collected as part of the As-Built View. This design feature allows the interception of cost-coded payroll data for speedy profiling of actual productivity – i.e., one does not have to wait for feedback from the cost accounting department. Figs. 13-15 highlight two other features of the daily site system that arise from integrating the Process, Physical and As-Built Views of a project. The submenu on Fig. 13 illustrates the opportunity to enhance system functionality by having it "mine" its own data in order to detect problem areas, and through the addition of expertise, to possibly suggest corrective actions (Russell 1998). Our current work in this area needs to be augmented by more fully integrating data from the Physical View into the corrective action reasoning process. Figs. 14 and 15 illustrate other opportunities from integration – that of superimposing data from the Process and As-Built Views in order to determine cause and effect and seek explanations for inadequate performance.

3 Conclusions and future work

We have found that the use of a multiple-view representation of a project contributes significantly to the integration of functions and the support of more functions than found in traditional construction management software systems

Future work will be directed at connectivity issues amongst the project views and on enriching the function set supported.

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226 THE PROJECT REPORTER: MULTIMEDIA PROGRESS REPORTING FOR CONSTRUCTION PROJECTS

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Abstract

The A/E/C industry is the largest US industry. It forms about ten percent of the dollar value of the US GNP, with a total annual volume for new construction exceeding $500 billion. Many of these projects are plagued with delays, over-expenditures, design changes, and other unexpected conditions jeopardizing the smooth and timely completion of the project. Regular and accurate reporting on project progress offers a continuous vital diagnosis of the project status, enabling different project team-members to make proper decisions on any necessary corrective actions to safeguard the project and ensure its completion. This paper discusses a new interactive multimedia system that can be used by different project team-members to document and report progress in construction projects, as well as a tool to analyze this progress and help predict the final project outcome. The interactive multimedia approach was selected to minimize the paperwork, provide timely update, and ensure a safe and easy method for document storage and retrieval. This research aimed at developing a practical and applicable tool to serve as a model of the interaction between academia and industry in the field of construction research and practice.

Keywords: Project management, internet, multimedia

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1 Introduction

Project progress monitoring and control is one of the most important tasks of construction project management. Every team-member needs to know, in a timely and accurate manner, how is the project progressing, where they are currently in comparison to the initially set plans, whether deadlines are met, budgets are respected, required quality is achieved, modifications are kept to the minimum, and safety measures are followed. It is mainly the responsibility of the general contractor (GC) to update the Architect/ Engineer (A/E), who, in turn, updates the owner. Under a construction management contract, this responsibility shifts to the construction manager (CM), who has to ensure that all project criteria are met, if not exceeded. This updating process usually takes the form of a periodic printed progress report (issued in most of the cases on a monthly basis), discussing the current versus planned status for the schedule, the budget, constructability problems, quality issues including test results, contract changes including modifications in design and increase/decrease in quantities, pending issues from progress meetings, as well as some pictures showing the current construction activities. Additional components like value engineering updates, safety matters, and weather conditions might also appear on these reports.

However accurate this report might be, the textual description in addition to the still photographic pictures cannot fully convey an exact image of what takes place on site, or show a dynamic and lively view of the construction activities. Once the project is over, the chance for using these progress reports decreases considerably. This may be partly due to the fact that storing and retrieving these reports, as well as sorting them and finding the required information is a tedious task in itself. Making use of the reports might be even more complicated by the deterioration in the condition of the original print of the report, together with changes in the company personnel and its organizational structure. These drawbacks of the printed report can be summarized in the following points:

1. By the time the report is prepared, reviewed, approved and submitted to the owner, it does not reflect the exact project status, as this process could take up to one reporting period (1 month).
2. Many of the problems faced on site can not be efficiently presented by textual or verbal descriptions alone.
3. The accuracy of recording and the timeliness of distribution of the minutes of meetings, with subsequent decisions depending thereupon, are usually disputed by different parties involved in these meetings, with each party trying to interpret any ambiguities for his or her benefit.
4. Photographic pictures can be altered to change their content or taken to conceal facts, which makes them an undependable source of information.
5. Problems faced in any particular project are normally not properly recorded or documented for future usage as lessons learned. Therefore, they might be repeated.

Therefore, there is a need for a different method of reporting progress, adding to the value of the printed report. Recent leaps in information technology and multimedia in particular offered a practical alternative for the printed reports. The purpose of this paper is to illustrate one effort to convert the text-oriented paper-printed static report into an audio-visual, interactive multimedia report that can be stored and distributed on a compact disk (CD) or on the Internet.

1.1 What is interactive multimedia?

Multimedia can be loosely defined as the use of information technologies as a controller of a variety of external media devices such as cameras, microphones, video recorders, compact disk and audio tape players and recorders for input and /or output. The computer serves as an integrator combining different media ranging from text, animation, video, audio, and still pictures or graphics, weaving them together into a consistent fabric. Multimedia in itself can be divided into two distinctive types: passive, also called linear, and interactive, also called non-linear. Passive multimedia does not allow for user interaction, while allowing only for one straight or linear path. A clear example for linear presentations is computer slide shows. Interactive multimedia (IM), on the other hand, allows for user interaction and feedback, and allows movement along several paths through links (also called hyperlinks) and buttons that trigger different actions (playing sound or video clips, moving to another part of the application, getting input from the user, etc.). It can be used for computer-based training (CBT), information kiosks, and educational applications.

The application discussed through this paper is based on the interactive multimedia type, to produce a paperless project progress report, the "Project Reporter".

2 Reporter development methodology

The development of the Project Reporter followed the steps listed below:

- Defining the structure of a progress report to reflect actual project status at any period.
- Selecting appropriate project management software packages to document project information including schedule, cost, quality, and contract administration.
- Designing the report including different media to be used.
- Data collection from real-life projects including progress meetings and review of various correspondences and project documents.
- Recording the project data in various media including editing and processing of different file formats (Audio, Video, and Virtual Reality).
- Compiling the final application and testing it in a real project to ensure its usability and applicability.
- Receiving feedback from users and performing needed modifications to the system based on the evaluation and feedback.
- Producing the final report including the findings and the results of this research.

2.1 Tools used to develop the project reporter

Several software and hardware tools were used to develop the technical content, as well as the presentation content of the Project Reporter. Among the tools used were:

2.1.1 Hardware tools and peripherals

- A camcorder for shooting live video (Construction activities and minutes of meetings)
- A digital still camera (To record project progress) and a tripod to stabilize the camera during shooting
- A video capture board (To digitize, i.e. convert from analog to digital, captured video)
- A recording microphone (To record overlay sound)
- A PC (Pentium 200 with MMX, 64 MB RAM, 5.1 GB HD, 17" monitor, sound card and speakers, and a modem)
- A CD recorder (to copy the compiled application for distribution)
- A Zip drive and Zip disks (For temporary storage of multimedia files)
- A color scanner (To scan documents and correspondence samples)

2.1.2 Software tools

- Multimedia authoring tool
- Video editing software
- Still picture editing software
- Still screen capturing software
- Screen sequence capturing software
- Image stitching software
- Sound editing software
- Scheduling software
- Contract administration software
- CAD software
- Animation software
- Web browser
- Microsoft office suite

2.2 Report structure

The report was structured to mimic the traditional text-based report in its main components:

- General information about the project and the different project parties
- Progress information including:
    - A summary of the current status of the schedule, budget, and expected completion date
    - Report on the current progress this period (since last update to date)
    - Report on the cumulative progress to date (Since the start of the project)
    - Report on the end forecast (Expected time and cost at completion)
- Technical details related to:
    - Constructibility issues
    - Design modifications
    - Unexpected site conditions
    - Quality measures
- Contractual measures including change orders and contract modifications
- Media section including:
    - Progress video clips reflecting different work items that took place during the report period
    - Edited recorded clips of the minutes of meetings
    - Panoramic (360 degree) pictures of construction activities with the ability of panning and zooming in and out
    - Sound files providing commentaries or descriptions of the work in progress.

A flexible navigation pattern was developed, enabling the user to move between the different components of the report with a minimum number of mouse clicks. This navigation pattern, shown in Figures 1 and 2, followed a main hub approach, represented by the main menu, with sub-hubs serving as the main access points for the other components of the report.

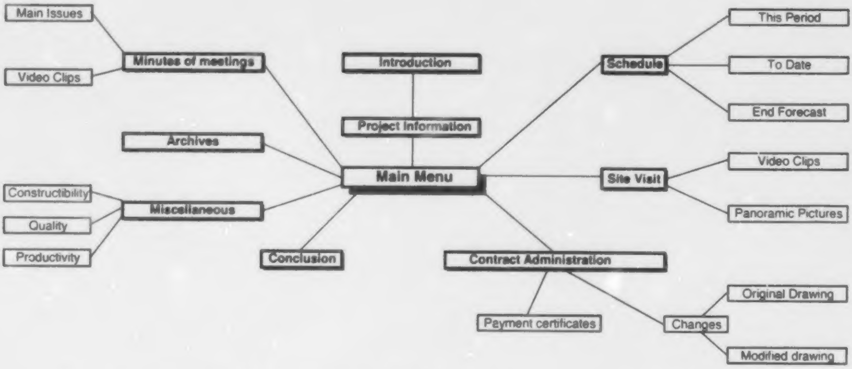


Fig. 1: Project reporter's navigation pattern

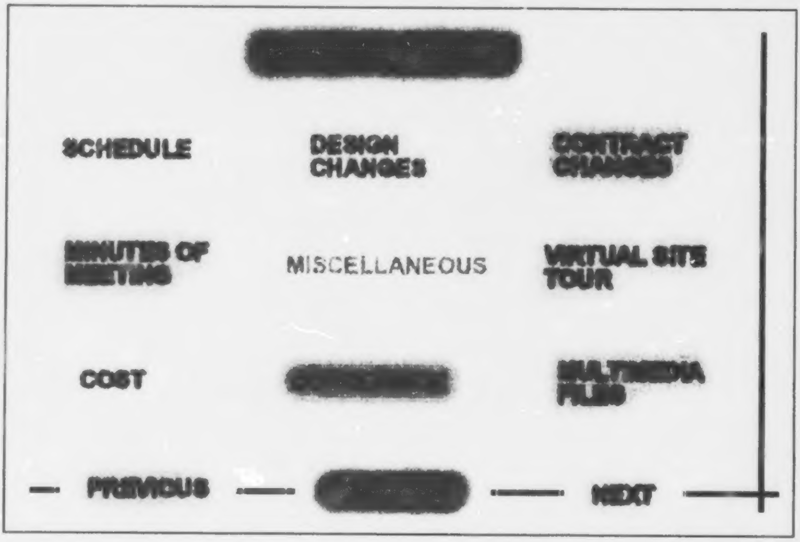


Fig. 2: The project reporter's main menu

2.2.1 Site Visit

Site visit is divided into two visual representations of the current work being done on site: (see Figures 3, 4 and 5)

- Digitized video clips: Which summarize the completed or under progress activities within the reporting period. These clips are sorted by location, trade, activity, and/or date.
- Panoramic pictures: also called vistas, which are 360 degree pictures, composed of several digital images stitched together to give the panoramic view. These vistas allow for panning and zoom-in and out. Several vistas were linked together through "hot spots", which are embedded hyperlinks enabling the user to move from one vista to another, showing a different view of the project from a different vintage point. Special windows were inserted inside each of the vistas, allowing the user to have a look at live video embedded inside the vista as he/she zooms in.

The combination of panoramic still pictures and live video allows for maximum interactivity and gives the feeling of "being there".

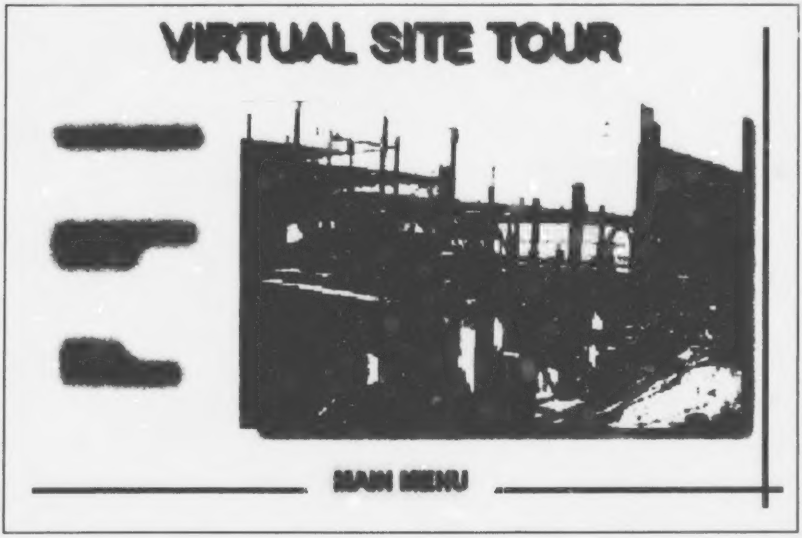
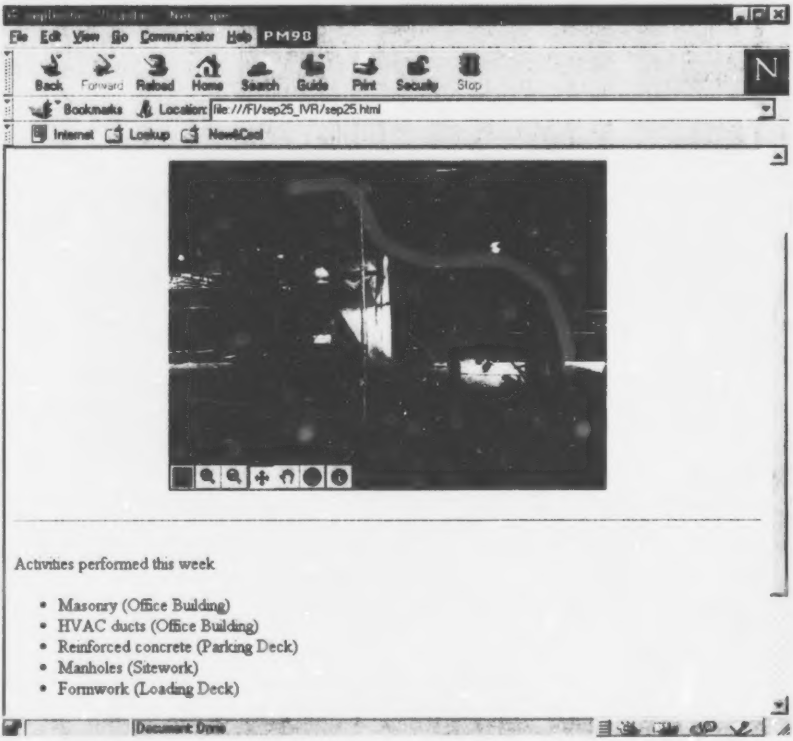


Fig. 3: Virtual site tour (Video)



Activities performed this week

- Masonry (Office Building)
- HVAC ducts (Office Building)
- Reinforced concrete (Parking Deck)
- Manholes (Sitework)
- Formwork (Loading Deck)

Fig. 4: Link to an Internet browser to show project Vistas and current activities

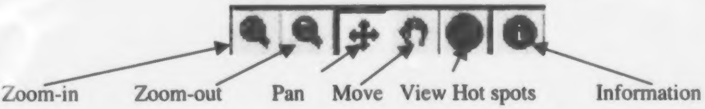


Fig. 5: Navigation panel within Vistas

2.2.2 Schedule

Through a textual description of the current status, a schedule shows percentage of completion, expected completion date, and comments on the progress in general (e.g. Concrete activities are 2 weeks behind schedule). A direct connection to the scheduling application is provided through using the OLE (Object Linking and

Embedding) properties linking (P3, Suretrak, Microsoft Project, etc). For example, OLE enables the user to view actual schedule data, as well as compare between actual and target schedules, in the form of a Gantt chart or a precedence network. This schedule module is divided into three main parts:

- This period: reflecting the progress achieved since the last progress update
- To date: reflecting the cumulative progress achieved from the start of the project to the date of the report
- End forecast: reflecting the expected project completion date, if the following performance trends are maintained. Any change in the expected completion date should not be construed as a change in contract conditions, but rather as a warning, in case of delay, that some corrective measure should be taken to restore the contracted completion date.

2.2.3 Contact Administration

Contract Administration: Shows any modifications to the contract documents, particularly the drawings in an electronic format (CAD files), and reflects any design changes and the potential impact of the change on the project schedule and cost. The original drawing is shown on one side of the screen, whereas the modified drawing is shown next to it, reflecting the design changes. This module also shows a copy of the latest payment certificate reflecting the value of the completed portion of the works, and the remaining balance till the end of the project, including past modifications to the project price through previously approved change orders. One of the concerns about releasing CAD drawings electronically is the issue of security and authenticity of the engineer's seal. Recent progress in encryption and electronic signature technology makes the release of these drawings safer. Additionally, it should be understood to all project parties that the electronic document is only a supplement to the printed one, not a substitute to it.

2.2.4 Minutes of meetings

Minutes of meeting show a textual description of the meeting agenda, discussed topics, and pending decisions. Video excerpts of the progress meetings for the reporting period can complement this textual description. The advantage of using video is the undisputed documentation of what has been discussed as well as what has been decided. It is worth mentioning that some of the project parties may show discomfort with the video-taping of the meetings, however, it should be brought to their attention that this is for documentation purposes, and that edited versions of the meeting can be sent to different parties for approval before being released.

2.2.5 Miscellaneous

This is a flexible module reflecting any issues related to project productivity, quality, or any Constructibility issues or problems. Value engineering change proposals (VECP) may be included in this module, reflecting any contractor-submitted changes to improve the project value.

2.2.6 Archives

This module reflects pending issues from previous reporting periods, as well as video clips and vistas from previous periods to reflect the gradual progress of the project. This module serves as the as-built chronological documentation of he project.

2.2.7 Conclusion

Including a final comment on the current progress report, any anticipated measures to improve performance, and any corrective measures to be implemented to remedy existing problems. This module serves as summary of the current period report, and a starting point for the next period's report. Graphical representations of different project trends were used to summarize the project status, especially for top management review.

3 Case study

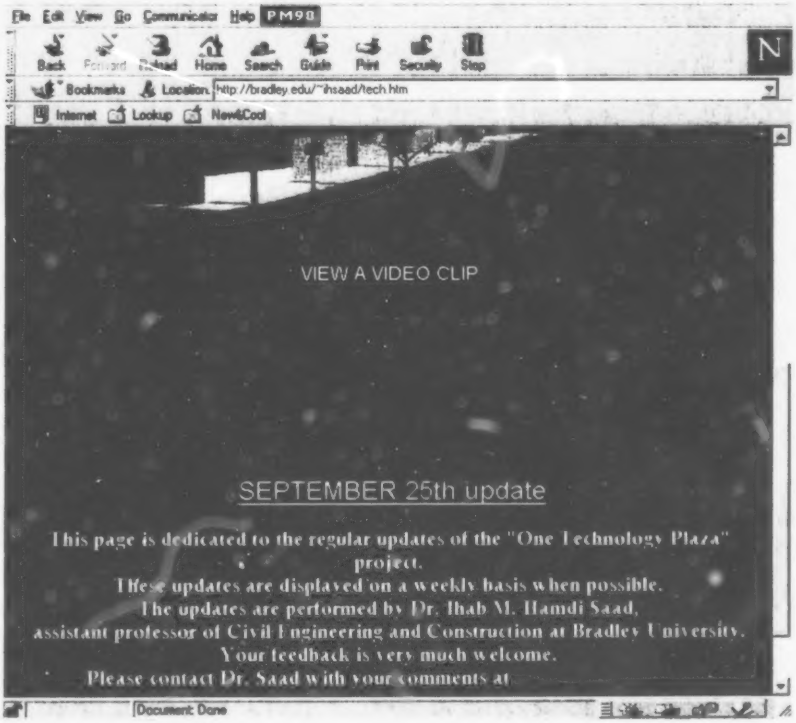
A specific project was selected as a case study for the development and testing of the Project Reporter. This project was the construction of an office building in downtown Peoria, Illinois, together with an adjacent parking deck. The office building is a seven-story steel structure, whereas the parking deck consisted of a five-floor reinforced, cast in-situ, post-tensioned, pre-stressed, concrete structure. The project was partnered between the main owner (Peoria City), the A/E (Clark Engineers), and the general contractor (River City Construction) who where all stakeholders in the project. The project was part of a larger project for restoring the riverfront of Peoria City to attract more tourists.

The first author was involved in the project as an observer, and attended the weekly coordination meetings between the A/E and the contractors, as well as the coordination meetings between the different owners.

4 Packaging and distribution

Due to the large size of multimedia files, video files in particular, the selected method for distribution was the compact disk (Read only Memory CD-ROM), which can contain up to 650 MB of data. Another method of distribution is the Internet, through Shareware or free plug-ins the user can download from the Internet, enabling review of most of the report (excluding video files) over the Internet; thus allowing timely distribution and sharing of the report. One of the advantages of the Internet over the CD is being independent of the platform (PC or Mac.). Another advantage was the ease and higher frequency of performing the updates and making them concurrently available (daily, semi-weekly, or weekly). Feedback about the report can be obtained through e-mail or IRC, completing the paperless cycle of the progress reporting.

A special web page was developed by the author for this case study, which was updated on a weekly basis, enabling the different project parties, particularly the top management of their different organizations, to view a panoramic picture of the latest progress status within the project. The web page contains 4 to 5 consecutive updates at a time, enabling the viewer to compare the progress from one week to the following one, and giving a brief idea about what activities took place on site during that week. The CM for this project (CMPI) linked this page to his own web site, as did the A/E (Clark Engineers), giving their different clients an idea about the project as a model on how communication and reporting could be done in a visual way on the Internet. The project web page includes short clips of video showing a morphing view of the ancient building that used to exist on this site, to its gradual transformation into the new building. Figure 6 shows a partial view of the project web page.



http://bradley.edu/~ihsaad/tech.htm

SEPTEMBER 25th update

This page is dedicated to the regular updates of the "One Technology Plaza" project.
These updates are displayed on a weekly basis when possible.
The updates are performed by Dr. Ihab M. Hamdi Saad,
assistant professor of Civil Engineering and Construction at Bradley University.
Your feedback is very much welcome.
Please contact Dr. Saad with your comments at

Fig. 6: Project web page for regular Vista updates

5 Discussion

Multimedia is a very flexible and promising tool for application in various fields, including construction project management. Timely sharing and exchange of information about project progress is of ultimate importance, especially in case of deviation from the initial plans, or any modification thereto, allowing for proper corrective measures to be implemented, as well as reassessment of the project budget, schedule, and contractual arrangements. Multimedia documentation of the project progress allows for increased perception of the actual project status, and allows for a safe and dependable way of storing historical project data for future reference and comparisons. Progress reporting is a multi-layered process, with different levels of details about the project status corresponding to different managerial levels of the stakeholders' organizations; brief and global view for top management, and detailed view for project management.

A web page was created to enable the project team members monitor the project progress remotely on a regular basis, allowing for comments and discussions. The web page was also used to post agendas for future meetings. A view of the web page dedicated to the vistas for progress updates can be accessed at:
http://bradley.edu/~ihsaad/tech.htm

227 INFORMATION TECHNOLOGY IN THE STRATEGY OF A MIDDLE-SIZED CONSTRUCTION COMPANY

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Abstract

This paper presents how Slavenburg's Bouwbedrijven B.V. uses IT in their Design/Build concept. This concept necessitates a migration in culture: moving from being a component in a production process, towards offering a total product. The paper presents experiential knowledge gained from implementing sophisticated computer tools, applications and networks in a middle-sized construction company. Some practical views of IT implementation are presented and discussed, including the selection of hardware platform, software suites, and applications. The advantages of centralised services are also discussed. In summary, the use of IT has provided new opportunities for the company and has helped the company's migration to Design/Build.

Keywords: Design/Build, data exchange, standards, workflow, enterprise resource planning, knowledge bank, document management

1 Introduction

Slavenburg's Bouwbedrijven B.V. operates throughout The Netherlands as a construction and development company and it is excessively specialised in offices and commercial real estate(Slavenburg 1999). The turnover in 1999 will be approximately 200 million Dutch guilders, or $100 million US.

Traditionally a midsize construction company is one of the participants in the chain between the project development and the facility management of real estate. As Slavenburg's Bouwbedrijven B.V. wants to become a leading Design/Build company in The Netherlands, and as such the only responsible partner dealing with the client; therefore close teamwork with other business partners of different disciplines will be necessary. There are several ways in which information technologies (IT) can help to achieve this strategy:

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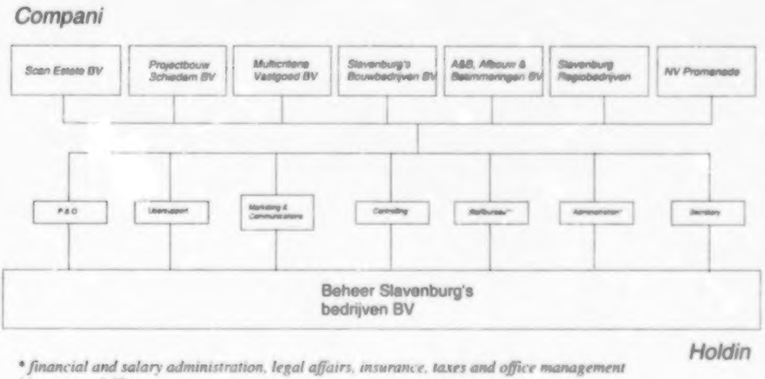
- Within the relation "costs / usefulness", using IT where possible.
- Improving the quality of the employees within the total context of Design/Build.
- Simplifying the primary process through:
  - Workflow management, especially document management and improving data information communication between the design partner and the next players.
  - Improved communication using modern technical tools.

1.1 The company organisation


Compani
Scan Estate BV
Projectbouw Schiedam BV
Multicriteria Vastgoed BV
Slavenburg's Bouwbedrijven BV
A&B, Afbouw & Betimmeringen BV
Slavenburg Regiobedrijven
NV Promenade
P & O
Usersupport
Marketing & Communications
Controlling
Stafbureau**
Administration*
Secretary
Beheer Slavenburg's bedrijven BV
Holdin

* *financial and salary administration, legal affairs, insurance, taxes and office management*
** *strategy & IT*

Fig. 1: The position of Slavenburg's Bouwbedrijven B.V. in the holding

Disciplines such as IT & Strategy, Human Resource Management, Office Management and Administration are centralised for the company. The companies, identified in Figure 1, are located in three cities in The Netherlands: Schiedam, Leerdam and Dordrecht. The companies have an average of 35 building projects at any given time. The company employs approximately 250 people, and augments their work with labour provided by subcontractors.

2 Design/Build: the idea

Design/Build means the complete integration between those two disciplines; as the construction company is a single point of responsibility for the entire process, it's important to communicate well with the architect.

To promote the idea of Design/Build, it is essential to know in advance "what are the needs and expectations of the client?" In the initial contact with a prospective client, Slavenburg's Bouwbedrijven B.V. uses a checklist, based on interviews with previous clients. Together Slavenburg's Bouwbedrijven B.V. and the prospective client fill in the detailed items, as well as functional requirements.

The final product of this stage, as the company sees it, should be an accumulation of a company's standard elements, based on experience, functional requirements, modern materials and techniques, etc. Each element on this accumulation is then classified in terms of comfort, quality and price. Together with accessories and material alternatives, these elements form the foundation on which the client makes choices and on which the architect assembles the design.

3 Choices in IT

To use IT in the chain from concept, design and construction through to maintenance, as well as to be responsible for the necessary information exchange, the first step is to have a solid information process supported by a reliable IT system within Slavenburg's Bouwbedrijven B.V.. In 1995, the company adapted a Total Quality Management (TQM) model and began to implement a strategy to replace our entire IT system: platform, operating system, infrastructure, hardware and software.

As Slavenburg's Bouwbedrijven B.V. is a contractor itself, being the only responsible partner dealing with the client, the company prefers to work with as few IT partners as possible. In order to be able to connect and to maintain the data exchange between new and changing partners in the future, the company is on the "lookout" for industry standards.

3.1 Information process

To build a solid information chain, a construction company needs both a solid organisation and series of processes. The information process runs parallel to the production process: both the primary processes and the secondary processes. To control the workflow, one must first integrate TQM with the organisation's logistic- and document management software. The second step is to put a shell of workflow management software around it and then you can implement top-down management information software.

3.2 Platform, operating system, infrastructure and hardware

Though Slavenburg's Bouwbedrijven B.V. was aware of the difficulties in maintenance, the company chose a client/server environment with a Windows NT Server as the operating system software. Scalability, integration and connectivity were the keywords for this decision. In a later stage, the company will want to fit in network computers as well. The company is now migrating from Windows 95 towards Windows NT Workgroup on the client workstations. The system configuration is presented in Figure 2. The LAN uses UTP category 5 with the speed of 10 Mb/s. If necessary this speed can be increased to 100 Mb/s. Data exchange between the company's three locations communicates by a 64 Kb/s connection with an ISDN-2 line as a backbone. Servers, workstations and portable computers are easy to reconfigure and are purchased from the same vendor, in order to reduce potential hardware and software conflicts.

3.3 Software

In the company's experience, the integration of several software packages is best done by using one database; in which all data, used by all the specific disciplines of a construction company, is only once and uniquely stored. Because the previous mini-computer system had reached its capacity in 1995, the company started the system replacement with new office management software first. Already using a number of Microsoft products, the choice for an office suite was not very difficult: namely, Microsoft Office. At that time the company could not find standard document management software. So a Microsoft Solution Provider built a customised system for the company, using FoxPro tables in a project-wise document storage system. It was given the name *Stonebuilder*. Our organisation did not buy a relational database at that time, because it was hoped that our logistic software would provide us with one in the future. To fill in the logistic part we looked for Enterprise Resource Planning (ERP) software supporting specific disciplines of a construction company. Our company finally selected the Baan business-model for the building industry. Most of the implementation of this software will be completed by the end of 1998. Workflow Management- and Management Information software are planned in future expansions.

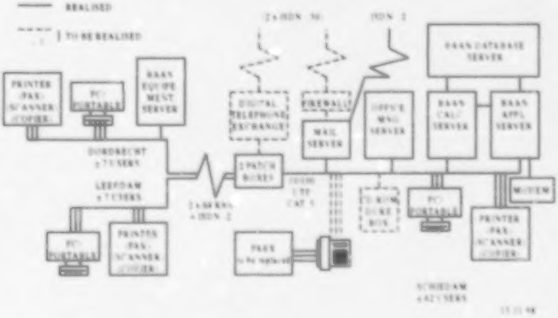


Fig. 2: Configuration Beheer Slavenburg's Bedrijven B.V

4 Design/Build: the realisation

The benefits of working with a totally new concept, such as Design/Build can be found in a number of areas: (1) clearing up bottlenecks, (2) improving procedures in the traditional way of designing and constructing processes, and (3) being creative by using modern knowledge and techniques. This paper discusses our achievements to date, as well as, Slavenburg's Bouwbedrijven B.V. current the action plan.

Table 1: User Software for domain disciplines

DISCIPLINE	SOFTWARE
Relation management	Baan IV
Graphic design	Corel Draw
Design	AutoCAD 14
Estimating	Baan IV
Project engineering	Baan IV
Execution	Baan IV
Project control	Baan IV
Invoicing	Baan IV
Purchasing	Baan IV
Accounting	Baan IV
Equipment control	Baan IV
Salary administration	CTB
Planning	Power Project
Office management + E-mail	Microsoft Office 97, Exchange Server, Proxy Server
Document management	Stonebuilder
Building maintenance	Spectrum
Facility management	-
Human resource management	Exact
Workflow management	-
Construction site	-

4.1 Human resources

In migrating a company from a more-or-less traditional culture to an innovating one, it is necessary to train the employees, to upgrade their skills, and to support them with up-to-date knowledge and documentation. In 1996, all our employees with a management function were trained to deal with changes. For example, in our Schiedam location, we have a centralised and up-to-date documentation centre, also using CD-ROMs. Effective March 1999, the company starts implementing a knowledge bank, using a full-text search engine on an Intranet and the Internet.

The increasing need for information, mostly fed by our own management and by government regulations, is due to the fact that more specific input data is required. During the construction, the construction site is the source of most of this input data. The skills of our site-managers are more practically based; and the site-manager is not an administrator. Therefore in April 1999, the company will implement specific IT-tools on the construction site, as a part of the Baan ERP software. The main intentions are to drive back most of the administrative handling; that is, data pertaining to the project, that is already in the our database, will be transferred to the construction site, so the site-manager only has to fill in the missing parts instead of filling out blank forms each week. This will also create a virtual entrance to the digital part of our documentation centre and our knowledge bank.

4.2 Communication

Attending meetings away from one's own office entails considerable time and travel costs.. In a small country such as The Netherlands, or in any large metropolitan area for that matter, there is considerable traffic, and therefore travel inefficiencies. Using techniques as E-mail, remote access, Intranet newsgroups, videoconferencing and an interactive web site can reduce these inefficient costs. The client as well as the project-manager or the architect will be able to communicate with each other at any time and with up-to-date information from a number of different sources:

- Logistic (Baan) database;
- Document database;
- Planning;
- Document centre;
- Knowledge bank.

Working with these shared resources and tools, it is necessary to protect information in such a way that employees can only delete, create, copy or read that information to which they are entitled . It also asks for a 'waterproof' office-, mail- and document management system:

- in order to deal with valid and up-to-date document versions;
- with central access of unique documents to avoid the creation of an E-mail copy-culture.

At the current time, the company is again looking for standard software which will fill this requirement so a pilot project can be started to realise our ideas and achieve our aims.

When our construction site automation has been successfully implemented, the company will start Electronic Data Interchange (EDI) with our suppliers and sub-contractors, using the same communication- and firewall tools.

4.3 CAD

The easier way to use data from the design partners in the rest of the chain, described earlier, is to work with compatible software. For the architect in the Slavenburg's Bouwbedrijven B.V. Design/Build product, the design should be completed using standard layers in AutoCAD. Unfortunately most architects prefers working with specific building-design CAD software inplace of AutoCAD. There are three arguments why the architect is against this kind of co-operation:

- Specific building-design CAD software is cheaper, because the user only needs buy one CAD software package instead of AutoCAD, in addition to specific building-design CAD application software;
- The architect can design faster with specific building-design CAD software (as fast as the manual colleague);
- In The Netherlands, an architect takes no responsibility on the exactness of the measures in drawings.

Most of the architects use standard CAD elements with which they put together their design.

Loyal at its Design/Build principles, Slavenburg's Bouwbedrijven B.V. started with creating its own standard elements in 1998. These elements were created in a specific building-design CAD application, are standard-layered, are AutoCAD based and are ready for 3D presentation. Taking full responsibility on the measures, the company engaged architects who want to use these elements in their designs, as soon as Slavenburg's Bouwbedrijven B.V. can provide them and, if necessary, the appropriate software. In the year 2000, the company expects to be able to use electronic design-data in the rest of the chain.

5 Conclusion

As the reader can see, even though an IT strategy can be formulated on paper, the difficulty is locating industry software standards and other communication tools, which can fill in the desired functionality and can integrate with each other. Slavenburg's Bouwbedrijven B.V. is now a contractor in on the European project: *Future Home* (1999) within this international context, working with a mixed team, the company expects to find new and innovative ways and possibilities, such as Virtual Reality (VR), to use IT in improving our Design/Build concept.

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228 AN ARCHITECTURE FOR HEAVY DUTY MACHINE CONTROLLERS — FORESEEING AUTOMATED ROAD CONSTRUCTION ENVIRONMENTS

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Abstract

Considering the architecture designed for the overall incorporation of information technologies (IT) on road construction environments, this paper focuses on the development of automated machine controllers, and on the underlying requisites of machines to use these controllers. Special attention is paid to the modules that compose the machine controller. This work was developed within European Project ESPRIT III 6660 RoadRobot (Operator Assisted Mobile Road Robot For Heavy Duty Civil Engineering Applications).

Keywords: Integration, interoperability, positioning systems, communication, controller.

1 Introduction

The integration of Information Technology (IT) into the Building and Construction (B&C) industry has not yet achieved a satisfactory degree of implementation. This industrial sector is still in strong need of IT, especially when considering major areas of the building industry, such as the outdoor construction of dams, roads, airfields and other large construction projects.

The results of the incorporation of state-of-the-art technologies into the building industry (especially when IT is considered) are still very poor. Most established developments are concentrated on the Computer-Aided Design (CAD), drafting, scheduling control of tasks, and automation of certain pre-fabrication processes.

No special attention has been given to the automatic data flow of planning and control information, or advocating about the business needs to the seamless flow of scheduling, resource, materials, and cost information between firms. For practitioners in these industrial environments, very often time and material planning are done in a manual process at the construction site in a standalone

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basis, most of the time assisted by data received on phone calls or paper support (Pimentão et al. 1994).

Even considering the research work, most of what has been undertaken regarding the development of overall control architectures for outdoor building sites is not noticeable, whereas the development of such control architectures for other industrial sectors has advanced significantly during the last years. The question is now, whether the results of the past developments can be transferred to the demands of the building and construction industry. The evaluation and improvement of architectures and modules coming from other industrial areas (Camarinha-Matos and Osório 1992) seems to be necessary.

For that reason, to learn from existing architectures and modules from other industrial areas, according the special requirements of the building industry, can help to find new ways towards fully or partly automated and integrated construction processes (Sousa et al. 1998).

Future developments have to focus on the integration of IT into the building industry (Bradley 1991). Besides the low-level automation of overall planning and control systems, the task-level programming of complete building sites has to be achieved. The main interest of future works lies in the development and elaboration of a generic architecture for standardised integrated indoor and outdoor construction sites. Therefore, further work should also be concentrated on the automation of specific heavy-duty machines (Ulrich 1991; Leidinger 1991) in order to obtain a manpower reduced building site, with computer integrated time scheduling and material planning possibilities.

The adoption of standards in modelling, using a specific data protocol to support the integration and flow of information using a unique data exchange format, to be adopted by the various activities in B&C environments is, for sure, a key factor where proposals are now starting coming out. Examples are the work being developed by STEP within ISO TC184/SC4 Building and Construction Working Group (STEP 1998), by International Alliance for Interoperability throughout its Industrial Foundation Classes (IAI/IFC).

2 The Road Robot's architecture

The purpose of the European ESPRIT 6660 RoadRobot (Operator assisted Mobile Road Robot for Heavy Duty Civil Engineering Applications) project was the definition of a flexible control architecture suitable for outdoor heavy-duty construction applications, towards an automated construction site involving mobile equipment, concerning the building industry requirements.

A flexible architecture for information flow and road construction management has been implemented, considering four logical levels: Site, Cell, Machine and Tool (Pimentão et al. 1993), as depicted in Fig. 1.

The process of road construction managing starts by loading into the RoadRobot Information System (IS) the information produced by a CAE system (in this case the InRoads from Intergraph), using a tool that we called "Project Development". Information is then decomposed and processed in order to produce the tasks.

Task decomposition is performed in a semi-automatic way with the aid of a

Decision Support System (DSS). Regarding a road section, the DSS looks at the geometrical and geological information and, based on a set of rules supplied by the experts (e.g. two-lane road produce a task per lane), and on equipment restrictions such as excavator arm length, to produce the tasks.

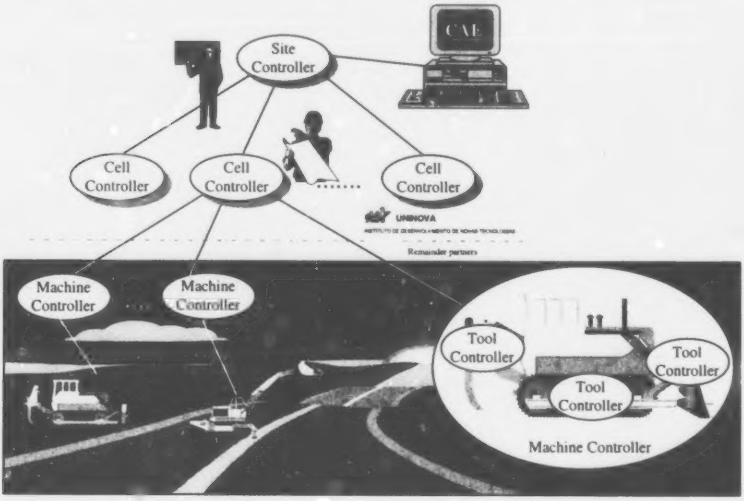

Fig. 1: Road Robot's architecture

Once task specification is accomplished, each task is then assigned to a given construction cell-type. Each task is set in the proper sequence, based on the knowledge of the road construction processes, with the aid of a "Planning tool" that assists the user on the sequencing and possible paralleling of tasks.

Cell types are based on the characteristics of the set of equipment that composes it (e.g. paving cell). Task scheduling follows it with the assignment of existing equipment to each cell and effective time scheduling. At due time, the Site Operator is supplied with the information needed for setting up the given Cell, and once the Cell reports its operational status, it is fed with the task information.

The process of planning and scheduling of tasks at the Cell level is performed in a similar manner, where each task is, in due time send to the machine controller for execution.

It is worth noticing the fact that at the Site and Cell levels, all tools have been integrated using the developed Road Model (RoadRobots' improvement over TNO's Road Model Kernel), which is an ISO 10303 - STEP model for representing information relevant for road construction processes. Also relevant is the fact that all communication among controllers (task assignment, control and execution status) has been included in the Road Model, which makes it (although subject to a strong revision) a model for the full construction process.

2.1 The Machine Controller

When considering an overall system to control the process of a given machine, the state of the art was, by that time, the fact that just some tools were regulated by means of control loops with complete lack of auto co-ordination. The settings for these tool controllers were not derived from the tasks to be performed, but set by machine operators using their expertise. This scenario kept the quality of the road very dependent on the experience and co-operation of the crew on and around the machines. Therefore, in order to change this situation an application independent part of the machine controller was defined in order to perform:

- Reception of tasks from the Cell Controller,
- Execution of commands from the Cell Controller and the machine operator,
- Controlling the process by monitoring and adjusting the process parameters when necessary,
- Signaling the machine operator and the Cell Controller when tasks are completed, aborted etc. and when any kind of problems occur.

This machine independent part interacts with the machine dependent, which is responsible by decomposing the given task in operations to be assigned to the tool controllers.

2.1.1 The Machine Controller's Architecture

The machine controller has been devised in two parts: machine dependent and machine independent. The following modules compose the later, depicted in Fig. 2:

- *Cell-Machine Interface*: the interface that allows the machine controller to receive task information and commands from the cell controller and manage the respective feedback;
- *Machine-Tool Interface*: the interface to the tool managers;
- *Knowledge based system*: the "heart" of the machine controller which, based on the machine dependent knowledge, processes information from a given task and translates it into tool parameters. It also has the ability to control the tool controllers on the performance of their assigned tasks;
- *Navigation System*: a module that supplies the machine controller with the machine's position and orientation;
- *User Interface*: an interface to the machine operator, mainly used to supply information, but that can be used also to control the machine in case of lack of communication to the cell controller.

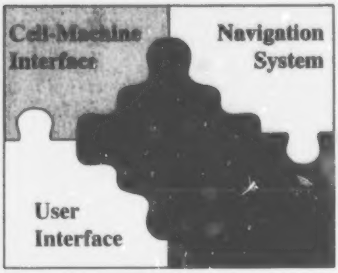

Fig. 2: The modules of the machine controller

2.1.2 A controllable machine

In order to implement the RoadRobot concept, the selected machines have to abide to some requirements (e.g. electrically driven tool controllers, sensors). For the Project one machine was chosen to demonstrate the concept in a real construction site – a paver machine from RoadRobots project leader, the German paver manufacturer VÖGELE AG.

When considering the automatic control of a road paver the Joseph Vögele company began, in 1990, to investigate alternative concepts to hydraulic drives for translation movements and rotary movements in order to achieve a more flexible and less expensive solution.

Even in the tough environment of a construction site and under extreme environmental conditions (temperature, humidity, dirt, corrosion), electric drives have been found to offer the following substantial technical advantages compared with hydraulic drives:

- Electric drives can be dimensioned according to output and torque.
- The variable speed range at constant output is so wide that the need for traction and shifting can be dispensed with.
- Even at a high driving torque its uniform motion at speeds close to zero is ensured.
- Electric drives have capability of temporary overload.
- Electric drives offer low-cost solutions for increased automation.

In conclusion and as result of these technical features the first completely electrical paver was produced under the scope of the RoadRobot project.

2.1.3 The Navigation system

The primary objective of the Navigation Module is to provide a rugged system that can determine the position of a mobile vehicle in five degrees of freedom (x, y, pitch, roll and yaw). The RoadRobot navigation system must be able to localise the vehicle to achieve accuracy over a large and unlimited operational envelope. Localisation of roll, pitch and yaw of the vehicle is required to a high accuracy.

A summary of the primary requirements identified for the Navigation

Module is listed below. These objectives were deemed to range from highly desirable to absolutely essential for construction vehicles in general.

- *High Static and Dynamic Accuracies*: the objective of the system is to locate the vehicle to a positional accuracy of <1cm or better in the translation parameters and 0.02 radians in the rotation parameters. These accuracies should be maintained for the vehicle moving with a velocity of 0.1 m/s in translation and 0.1 radians/s.
- *Robust, Capable of all-weather operation* without loss in performance and capable of working in a wide range of environments (built- up, in tunnels)
- *Applicable to a wide range of vehicles.* In order to capture the widest possible market, the Navigation Module should be applicable to other type of vehicles. In order to meet these requirement features such as: Low-cost, compact size, low-maintenance, weather-proof are all factors.

There were a large number of navigation systems available on the market (CTS, GPS, radio-based navigation and laser-based positioning systems), however none closely matched the RoadRobot's navigation system requirements.

Laser-based systems have been a viable proposition in relatively low cost mobile robotics for some time now. Most of these sensors use a laser to find the absolute bearing of a bar code in the environment, however some use retro reflective material attached to beacons to determine their relative bearing. A small number of these sensors provide both range and bearing to the retro reflective beacons One disadvantage with using beacons is that they need to be placed at regular locations in the environment before vehicles can operate.

As a result a number of sensors with radically differing modalities, including a laser-based scanner, were identified as having combined potential to meet the requirements of the objectives, provided they could be made to work together as a complete system. The decision was made to develop a system using existing sensors whose information was pooled together using well understood State Estimation principles. State estimators provide a mechanism for integrating various forms of sensor data, which only provides indirect information on the state that is being estimated, and refining the state or position of the vehicle. The system produced can take data from a variety of low-cost sensors and can, using smart algorithms, generate information that is of significantly higher quality than that provided by individual sensors.

The resulting system includes a combination of single ended GPS, laser-based beaconing systems and a low cost inertial sensor and it is controlled by and provides navigational information to the Machine Controller via a serial communications link.

The produced system technical specifications are presented in Table 1.

The specification achieved is quite acceptable for the construction site vehicles in general.

The Navigation Module is mounted on top of the RoadRobot vehicle where it has a clear line of sight to fixed retro-reflective beacons that have been placed in the surrounding environment.

Table 1: Technical specifications of the navigation system

Parameter	Value
Positional Accuracy	1 cm
Orientation Accuracy	20 mrads
Max- Vehicle Rotation Rate	0.1 rads/s
Max. Vehicle Velocity	0.1 m/s
Mm. Navigation Update Rate	10 Hz
Max, Laser Sensor Range to Beacon	30m

Once the beacons have been placed in an acceptable layout their positions need to be determined. After placement, the positions of the beacons need to be determined accurately, this is done using a theodolite and traditional surveying techniques. These positions are then given to the navigation system.

A minimum of three beacons is required to maintain the stated accuracies. Ideally, the operator would configure the beacons so that the vehicle could always see the maximum amount of beacons that are equally spaced around the vehicle. It is also better to have the beacons well spread, rather than in clusters.

2.1.4 The knowledge based system

It was decided that, at machine controller level, the application of AI-techniques for processes that are not totally understood.

Process knowledge must be acquired from the operators, and by modelling the processes themselves and their interactions. Several techniques were developed for knowledge engineering, which gained an increased level of importance.

A recent application field for expert systems is the use in real-time control applications. To this purpose it was necessary to combine of rule-based systems, fuzzy logic and neural networks. Fuzzy logic and neural networks were used to control the real-time aspects of applications, while the rule based systems were used for the high-level control of an application.

The knowledge about the control of the process is kept as rules, which can be updated without having to re-organize the entire software.

2.1.5 User interface

The available graphical user interfaces provided standard control and outlook of PC applications. Problems arose with the realisation of dedicated graphical representation of the machine tasks and statistics. These have been solved by the use of a flexible, graphical user-interface programming environment.

The Local User Interface realised in the RoadRobot project represents a flexible, high performance state-of-the-art graphical interface. It allows controlling and monitoring the machine operating process in a very user-friendly way.

The Local User Interface is an integrated part of the Machine and Tool Controllers and provides, as such, the opportunity to enter markets such as machine control integrated with shop floor information systems. The real-time visualisation of the physical process, together with the user-friendly interaction with the operator supported by the use of a touch screen system, optimises the interface between operator and machine. This combination gives added value to a standard graphical user interface.

2.1.6 Communication infrastructure

The machine controller has two types of interfaces: one with the Cell Controller and the other with the Tool controllers.

a) Cell-machine interface

The main problem that arose was the communication between cell controller and the machine controller, given that the former was supposed to be positioned in a fixed location whereas the later is moving around with the machine.

For the physical communication problem a Radio Frequency (RF) solution was selected, nearly without consequences for the software application. The only restriction is on long distance communication, where the quality of the signal is poor, limiting the baud-rate. However, for short distance communication, up to 100m, it can deliver a baud-rate up to 1 Mbit/sec.

At the logical communication level TCP/IP protocol family was selected, which allows for an overall communication infrastructure from the Site Controller down to the Machine Controller.

b) Machine-tool interface

The existing control systems implied that a change of the type of machine or parts of the equipment always required a lot of implementation work. To this end, more flexible process control was requested by the end-user of the machines. The development of an architecture, which follows the principle of distributed intelligence for a group of automated functions, helps to reduce the work in this area. Due to the fact that now an independent working processor controlled one process group, a whole process group can be added or eliminated just as required. This development was enabled by the use of a fieldbus system that allows the exchange of the process control parameters and the flexible composition of several process modules.

The objective to reduce the repair costs in case of malfunction has been considered by the identical hardware construction of the process modules. They could be easily exchanged. The specific working program is then transferred via the fleldbus system and adapts the module to the process specific working.

3 Conclusions and acknowledgements

At the start of the Road Robot project, the quality of the road was largely dependent on the know-how of the persons involved. If the teamwork did not work efficiently, large amounts of money had to be spent in order to correct the failures. That was the reason for the requirement of automated system, which should provide a constant quality.

The developed architecture and the data integration achieved has proved to be a requirement for substituting and improving, with reliability and performance, the manual and/or repetitive procedures.

This project had a major challenge, based on the need of applying and sometimes developing technology (applications, communications and hardware) towards the full automation of tasks that are usually performed/controlled by humans.

The use of standards in the modelling process helped to proceed towards automated and integrated construction sites, by integrating the actors in the different levels of participation, both exchanging data among applications and sending messages for control of the process. Standards like STEP, IAI/IFC are examples of those that can contribute positively for the intent. The results achieved during the RoadRobot project stress these conclusions, based on experiences executed under real conditions. (Gonçalves et al. 1996).

Based on the results of RoadRobot, the consortium designed a world-wide new road paver concept, which was used to pave the first road without direct human intervention.

We would like to thank, without exception, all the partners working in the Road Robot projects' consortium and, in particular, we acknowledge the European Commission by the financed budget and its support and trust in our ideas and developments.

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229 AN AUTOMATED MODEL FOR GENERATING A SHORT-INTERVAL SCHEDULE

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Abstract

Many problems occur on the construction site during the execution of the project. Some of these problems are due to a lack of detailed planning and scheduling. Although Short-Interval Scheduling (SIS) has proven to be a useful technique in managing the day-to-day work at the construction site, this technique is not extensively used. One of the reasons for this is the time consumed in the development of these schedules. This paper discusses the benefits of Short-Interval Schedules. Current manual SIS formats are presented. The paper introduces an automated model that will allow for the generation of Short-Interval Schedules.

Keywords: Construction, project, developing, schedule, goals, format

1 Introduction

Construction Scheduling is a major tool for the management of projects. Over the past decades, it has served as a fundamental basis for monitoring and controlling project activities. Although the use of this tool has enhanced the performance of the construction team and has helped them in executing projects more efficiently, studies have proven that a considerable amount of the eight-hour day is non-productive time, especially due to "waiting" time [Adrian]. This "waiting" time is characterized by events such as a laborer waiting for materials or equipment, a worker waiting for the help of another worker, a subcontractor waiting for the general contractor or vice-versa, and so on. The majority, if not all, of the non-productive time related to "waiting" can be traced to a lack of detailed planning and scheduling [Adrian].

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During the implementation of the project, personnel involved in the actual execution of the work need a breakdown of the scheduled activities into more detailed tasks or work items with information on daily quantities and resources required. This allows for planning and managing the day-to-day work at the construction site more effectively. It also helps the project team to eliminate, or at least reduce, the non-productive time related to waiting, and to remain on schedule.

Normally, the main construction schedule does not contain sufficient detail to represent tasks on a daily basis. Due to the nature and long time periods needed for implementing construction projects, the scheduler has a limitation of details when developing the project network in order to keep the schedule practical to use. The scheduler then implements the main schedule with a certain level of detail depending on the complexity of the project and the intended user of the schedule. The average duration of any activity presented in the main schedule usually varies from 5 to 15 days, and sometimes double these figures. Including more activities at a higher level of detail and shorter duration may result in a more complicated schedule that is impractical to maintain. In addition, the construction project environment is inherently dynamic. It is impractical, if not impossible, to predict all aspects of the project prior to starting construction, and inevitably things do not always go as planned. With a large number of activities and subactivities implemented in the main construction schedule, it becomes tedious and time consuming to update the schedule whenever changes occur.

Developing SIS from the main schedule is advantageous to planning and managing the day-to-day work more effectively. Abstract information represented in the main schedule needs to be extracted. This information can then be expanded and used to reschedule, in detail, the daily/weekly tasks in order to meet the project team's short-term goals and objectives. The SIS won't substitute for the main schedule, but rather, it will be its compliment. The SIS has several advantages. It helps to increase the productivity by eliminating, or at least reducing, the non-productive time related to "waiting". Having the resources and materials ready on site, whenever needed, is one of the main benefits of SIS. It also instills in both workers and superintendents an immediate sense of urgency to get the job done. The effect is psychological and occurs because SIS establishes obtainable goals on a short-range basis. The short-range aspect is what makes the goal attractive and challenging.

The concept of SIS is not new. It was developed in the 1930s as a management technique to control the output of workers in manufacturing. It was known as a method for assigning a planned quantity of work to be completed by a specific time, and as a means to determining whether the quantity of work has been completed within the specified time limit [Kerzner, 1989]. Then it was introduced to the construction industry. It is explicitly recognized by several scheduling methodologies that have been available for many years and have been called by a number of names, such as: Short-Interval scheduling [Behan, 1966; Smith, 1968]; Short-term goal setting [Hadavi and Krizek, 1993], Shielding Production [Ballard and Howell, 1997].

Several experiments and research efforts have proven the necessity and impact of applying SIS on construction projects. They have concluded that short-term goals resulted in higher productivity than long-term goals [Hadavi and Krizek, 1993], and that, for construction crews, the largest categories of reasons for failure are missing materials and failure to complete prerequisite work [Ballard and Howell, 1997]. In addition, several case studies have also reflected the benefits of using SIS [AGC, 1994].

However, Short-Interval schedules have usually been implemented for only a limited part of the project. This is due to the time consumed in the development of these schedules, as well as the difficulty of updating them whenever changes occur. In addition, manual goals set by the foreman could sometimes be too easy to achieve, because he does not want to commit himself to difficult goals [Hadavi and Krizek, 93]. Thus, an automated model that uses information predetermined by the management can assure the quality of assignments given to the crew.

The next section presents an overview of current manual formats used in the management of construction projects. The following section presents an automated model that allow for the generation of SIS to assist the project team in managing and controlling day-to-day work. The model utilizes construction assemblies/components database to intelligently develop the Short-Interval Schedules.

2 Current SIS formats

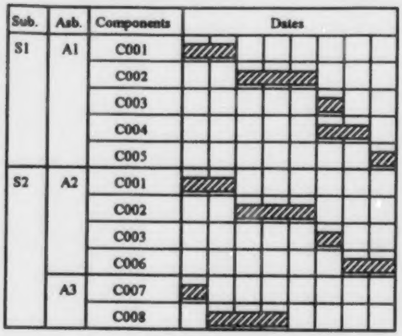
Depending on the quantity of work included in the activity, the process of developing a detailed schedule begins with breaking down the activities from the main schedule into subactivities that have smaller quantities, and/or assemblies. Then each assembly is divided into more finite details with components or work tasks.

- *Subactivities*: Depending on the quantity of the work contained in the activity in the main schedule, activities could be divided into several sections according to geographic location in the project. In this case, a portion of an activity called a subactivity represents each section. For example, a 10,000 ft^2 concrete slab could be divided into four sections of 2,500 ft^2 each.
- *Assemblies:* An assembly is the functional element of the building. It is a grouping of several building components. Each assembly has its own specifications. Activities and subactivities constitute one or more assembly. For example, a "construct footings" activity, or a "construct footings – Area A" subactivity, could be divided into two assemblies: "spread footings" and "strip footings".
- *Components or work tasks*: A component is the fundamental unit of work in a project. It has a concise description of the work to be performed. For example, a "Cast-in-place beam and slab, two-way" assembly includes the following components: "forms in place, flat plate", "forms in place, exterior spandrel", "forms in place, interior beam", "reinforcing in place", "place and vibrate concrete", "finish floor", and "cure".

Fd

Their exist several formats to present detailed scheduling. Each format has its advantages and disadvantages. The different formats are:

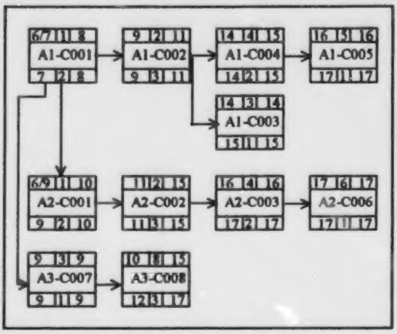
- *Bar Chart schedule* (Figure 1a) is developed in exactly the same way a main project Bar Chart is developed, thus has the same advantages and disadvantages. It is easy to implement, but does not represent the relation between the components.
- *Date List* (Figure 1b) is a list of start and finish dates given to each component. It presents exactly the same information as the Bar Chart, although not as clearly,
- *Network schedule* (Figure 1c) is developed in exactly the same way a main project network is developed. It is a very complicated and time-consuming tool to be used in detailed scheduling, especially with the great number of components activities can be broken down to. If an activity has 6 components that have to be done in four places. The result will be a network of 24 components just to breakdown one activity.
- *Matrix schedule* (Figure 1d) is a table where columns represent dates, rows represent subactivities, and cells represent different components. Each table usually displays one activity. This format is most effective when the activity being scheduled need to be broken down into subactivities, then into components. However, it is difficult to understand the logic behind this format if you are not its developer.
- *Graphic schedule* (Figure 1e) a graph that represents subactivities in their real geographical location in the project. Each subactivity contains its components. The logic between the subactivities is presented by arrows. The graph contains the same information as that contained in the Bar Chart and the Date List.
- *Short-Interval Scheduling form* (Figure 1f) is a table that represents the components to be performed for a specific duration, as well as the quantity and the resource needed for each component. The advantage of this form is that it contains more information than any other format. Although, it does not contain the logic between the components.



(a) Bar chart schedule

Sub.	Asb.	Components	Duration	Start	Finish
S1	A1	C001	2	6/7/99	6/8/99
		C002	3	6/9/99	6/11/99
		C003	1	6/14/99	6/14/99
		C004	2	6/14/99	6/15/99
		C005	1	6/16/99	6/16/99
S2	A2	C001	2	6/9/99	6/10/99
		C002	3	6/11/99	6/15/99
		C003	1	6/16/99	6/16/99
		C006	2	6/17/99	6/18/99
	A3	C007	1	6/9/99	5/9/99
		C008	3	6/10/99	6/15/99

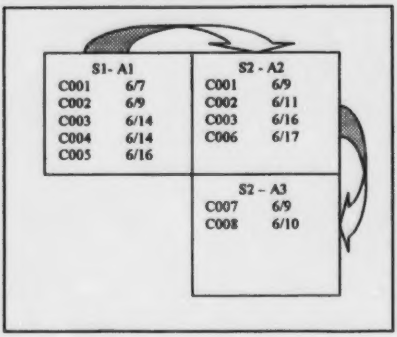
(b) Date list



(c) Network schedule

Sub		Dates										
S1	A1		C1	C1	C2	C2	C2	C4	C4	C5		
								C3				
S2	A2		C1	C1	C2	C2	C2	C3	C6	C6		
	A3		C7	C8	C8	C8						

(d) Matrix schedule



(e) Graphic schedule

S/A	Comp	Date	Quantity	Manpower	Equipment	Material
S1/A1	C001	6/7	2.56 c.f.	••••	••••	••••
S1/A1	C002	6/9	5.11 c.f.	••••	••••	••••
S1/A1	C003	6/14	1.5 s.f.	••••	••••	••••
S1/A1	C004	6/14	6.74 c.f.	••••	••••	••••
S1/A1	C005	6/16	7.21 c.f.	••••	••••	••••
S2/A2	C001	6/9	2.56 c.f.	••••	••••	••••
S2/A2	C002	6/11	5.11 c.f.	••••	••••	••••
S2/A2	C003	6/16	1.5 s.f.	••••	••••	••••
S2/A2	C006	6/17	9.82 c.f.	••••	••••	••••
S2/A3	C007	6/9	2.61 c.f.	••••	••••	••••
S2/A3	C008	6/10	4.43 c.f.	••••	••••	••••

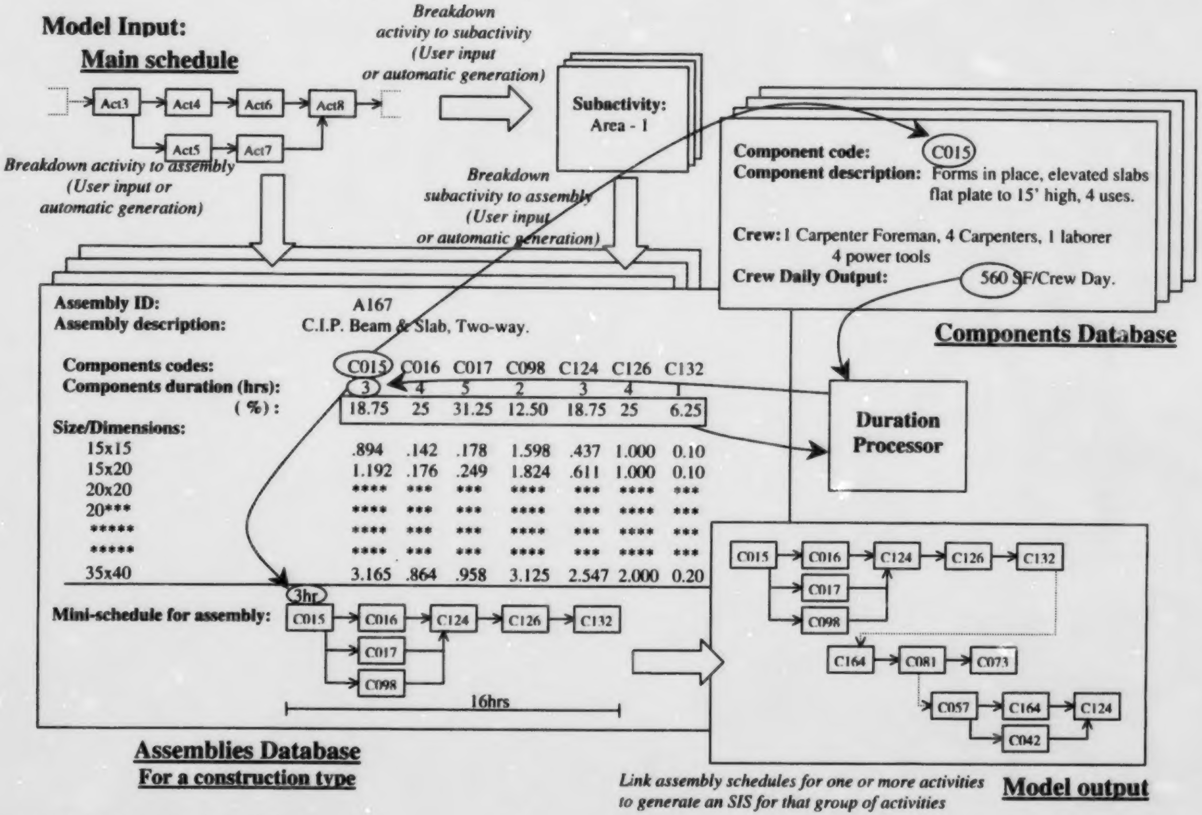
(f) Short-Interval scheduling form

Fig. 1: SIS formats

3 The proposed model

The proposed model will allow for the generation of a Short-Interval Schedule to help in more effectively planning and managing the day-to-day work at the construction site. Its main objective is to facilitate the development and the updating of these schedules. A proposed model for generating SIS from main schedules is depicted in Figure 2.

Based on project specific information, activities in the main schedule are broken down into subactivities and/or assemblies. This process may be accomplished manually through user input or automatically through intelligent interpretation of construction knowledge about activities, assemblies, and work items (components).


Model Input:
Main schedule
Act3
Act4
Act6
Act8
Act5
Act7
Breakdown activity to assembly (User input or automatic generation)
Breakdown activity to subactivity (User input or automatic generation)
Subactivity: Area - 1
Breakdown subactivity to assembly (User input or automatic generation)
Component code: C015
Component description: Forms in place, elevated slabs flat plate to 15' high, 4 uses.
Crew: 1 Carpenter Foreman, 4 Carpenters, 1 laborer 4 power tools
Crew Daily Output: 560 SF/Crew Day.
Components Database
Duration Processor
Assembly ID: A167
Assembly description: C.I.P. Beam & Slab, Two-way.
Mini-schedule for assembly:
3hr
C015
C016
C017
C098
C124
C126
C132
16hrs
Assemblies Database
For a construction type
C164
C081
C073
C057
C042
Link assembly schedules for one or more activities to generate an SIS for that group of activities
Model output

Components codes:	C015	C016	C017	C098	C124	C126	C132
Components duration (hrs):	3	4	5	2	3	4	1
(%) :	18.75	25	31.25	12.50	18.75	25	6.25
Size/Dimensions:							
15x15	.894	.142	.178	1.598	.437	1.000	0.10
15x20	1.192	.176	.249	1.824	.611	1.000	0.10
20x20	****	***	***	****	***	****	***
20***	****	***	***	****	***	****	***
*****	****	***	***	****	***	****	***
*****	****	***	***	****	***	****	***
35x40	3.165	.864	.958	3.125	2.547	2.000	0.20

Fig. 2: The proposed model's diagram

An assembly database for the model will be defined and will constitute various generic construction assemblies and needed construction information. A component database will also be defined and will contain information on construction work items. Information such as crew description and daily output will be stored in the components database.

Each activity/subactivity will be associated with one or more assembly. Each assembly will comprise of one or more component. A component code allows identifying the different components that constitute each assembly and their corresponding production information. Durations and percentage contribution of each component toward execution of each assembly will be calculated, and a mini-schedule of the assembly is generated.

The model output should include a set of mini-schedules for assemblies considered as shown in Figure 2.

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PART SEVENTEEN

DECISION-SUPPORT SYSTEMS

230 DATA WAREHOUSING IN THE CONSTRUCTION INDUSTRY: ORGANIZING AND PROCESSING DATA FOR DECISION-MAKING

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Abstract

Construction organizations are critically dependent on data. But data must be available in suitable forms for use. Timely access to useful and meaningful information can enable construction companies gain competitive edge, increase client satisfaction, expand market share and enhance profitability. Vast amounts of construction operational data are scattered across multiple, dispersed and fragmented departments, units or project sites. In this paper, we present data warehousing as an emerging database management technology that can provide the resource for decision-making. We point out the difference between an operational database - used for transaction processing; and a data warehouse - intended to be used for analytic processing in management decision-making in the context of construction organizations.

Keywords: Database management, data warehousing, construction organizations, decision-making

1 Introduction

Effective management of construction projects and, for that matter, construction organizations is critically dependent on the effectiveness of the decision-making process used by the organizations. Most often, the process is informal and unstructured and sometimes arbitrary. Although, ideally, decisions should be based on data and information, in practice they seldom are. Conventionally, data are viewed as a resource that supports transaction processing in an organization. Transaction processing involves day-to-day operations of an organization. In a

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typical construction contracting company, payroll processing, time card processing, materials management, estimating, scheduling, and routine activities like these are examples of transaction processing. The concept of normalization was developed to facilitate organization, maintenance and utilization of data for supporting transaction processing in organizations.

While normalized data are essential for supporting day-to-day transaction processing, they are not as useful to upper level decision-makers. Data should be organized in a different way in order to satisfy the need of the decision-makers. The recently introduced concept of data warehousing may provide a solution to the need.

2 Data warehousing fundamentals

Construction organizations generate and use vast amount of operational data that are distributed across various functional databases. For the most part, however, the fundamental value of these scattered data remains uncovered and unutilized. Decision-makers often have to wait days or weeks for responses from IT (information technology) or MIS (management information system) personnel that handle requested database queries in order to tap into such data. Such long waiting periods can cause irreversible damages to the reputation of a construction organization. Accessing the appropriate information from these databases at the time when it is needed, and in the appropriate format, is not an easy task. Data warehousing is presented in this paper as a concept that is meant for gaining timely access to these data in order to facilitate effective decision-making.

According to Inmon (1992a), data warehousing is a collection of decision-support technologies, aimed at enabling the "knowledge worker" (executive, manager, and analyst) to make better and faster decisions. The primary purpose of a data warehouse is to provide easy access to specially-prepared data that can be used with decision-support applications, such as management reporting, queries, decision-support systems, and executive information systems. Data warehousing is broad in scope, including:

- Extracting data from transactional systems, operational systems and other external sources;
- Cleansing, scrubbing, and preparing data for decision-support;
- Maintaining data in appropriate data stores;
- Accessing and analyzing data using a variety of end user tools; and
- Mining data for significant relationships.

Obviously, data warehousing involves technical, organizational, and financial considerations. Data warehousing technologies have already been successfully deployed in many industries. According to Adriaans and Zantinge (1996), data warehousing is being effectively-used in manufacturing for order shipment and customer support, in retailing for user profiling and inventory management, in financial services for claims analysis, risk analysis, credit card analysis, and fraud detection, in transportation for fleet management, in telecommunications for call analysis and fraud detection, in utilities for power usage analysis, and in healthcare for outcome analysis

In this paper, the potential role of data warehousing in strategic decision-making with special reference to construction organizations is discussed. A review of the differences between operational database and that of the data warehouse, the general architecture of the data warehouse, and online analytic processing (OLAP) used to analyze data extracts from the data warehouse, as opposed to online transaction processing (OLTP), are presented. Finally, benefits that could potentially be derived from data warehousing implementation within a construction organization are presented.

3 Understanding data warehousing

In general terms a data warehouse is a database created by combining data from multiple databases for the purposes of analysis. A data warehouse is used solely for reporting purposes unlike the traditional data capture or online-transaction processing (OLTP) systems such as general ledger, accounts payable, financial management, order entry, or equipment inventory. A data warehouse is populated with data from two sources. The most frequent source is the periodic migration of data from OLTP systems. The second source is from externally purchased databases such as list of incomes and demographic information that can be linked to internal data. The warehouse gives management the ability to access and analyze information about its business. It allows users to utilize business and market information for directing corporate objectives. The data warehouse collects all of the data into one system, organizes the data so it is consistent and easy to read, keeps "old" data for historical analysis, and makes access to and use of data easy so that users can do the analysis themselves (Corey *et al*. 1998).

From the above general discussion, data warehousing can be defined as a *subject-oriented, integrated, non-volatile, time-variant* collection of data for supporting the process of management decision-making (Inmon 1992c). Understanding these key characteristics of data warehouse is crucial for the understanding of how it can be effectively used to facilitate efficient and effective decision-making

3.1 Subject-oriented data

A data warehouse is established around all the existing applications of the operational data of an organization and it gives information about a particular subject about an organization's on-going operations (e.g., equipment, supplier, orders, shipments) instead of around applications (e.g., general ledger or payroll). Since the data warehouse is designed specifically for decision-support while an operational database contain information for day-to-day use, not all the information in the operational database is useful for a data warehouse.

3.2 Integrated data

In an operational data environment many types of information used in a variety of application may be found and different names for the same entity may exist. The data warehouse reconciles the different data representations in various operational databases used by the organization. To create a useful subject area, the source data must be integrated by modifying it to comply with common coding rules. The data warehouse gathers data into the warehouse from all these variety of sources and merges them into coherent whole. In this way they reflect the business information of the organization.

3.3 Time-variant data

Most business analyses are, in fact, analyses of trends. Trend analysis requires access to historical data. The data warehouse stores data that can be identified with particular time periods.

This implies that there must always be a connection between the information in the data warehouse and the time it was entered. The data warehouse therefore maintains historical data (typically three to five years of data) to enable the knowledge worker to do trend analysis over time. Operational systems on the other hand, are designed for immediate response and therefore data is often purged within a few months of its capture.

3.4 Non-volatile data

Data in the data warehouse are never updated, but only used for queries. It contains stable data, which are normally read-only environments that are enriched only on a nightly, or weekend basis. In this way such data can only be loaded from the operational database of the organization since that is the only database that can be updated, changed or deleted. Because the data are non-volatile in the data warehouse, management gets a consistent picture of the state of affairs of an organization's business.

4 Decision-support versus transaction processing

The data warehouse is maintained separately from an organization's OLTP databases to reduce the impact that queries have on operational systems and to safeguard operational data from being changed or lost. It also allows database administrators to combine fields from different systems to create new, subject-oriented data that "end users" can access directly using powerful graphical query and reporting tools. Another reason for separating the data warehouse from an organization's OLTP databases are that the data warehouse supports on-line analytical processing (OLAP) which enables users to leverage the information stored in databases for sophisticated decision-support analysis. The functional and performance requirements of these systems are quite different from those of the OLTP applications traditionally supported by the operational databases (Zhuge *et al.* 1995). The operational database is clearly in the operational environment with data entering into it from unintegrated environment applications. Once the data have been successfully populated into a well-designed data warehouse they can then be made available to all the management decision-support systems in the organization, such as management information systems (MIS), executive information system (EIS) and decision-support systems (DSS). With such major differences in the two environments, technology for supporting them should also be different (Adriaans and Zantinge 1996).

Since the data warehouse is designed specially for decision-support queries, only that data needed for decision-support are extracted from the operational database and stored in the data warehouse. Traditional OLTP systems, designed to handle day-to-day mission critical data and to have access to information through simple query operations, are very good at putting data into the databases quickly, safely and efficiently but not good at delivering meaningful analysis. Retrieval of facts for a typical *ad hoc* report takes too long to specify and convey to an IMS (information management systems) organization, with even a longer wait as a result. Operational systems, therefore, can not serve as repositories for facts and historical data for business analysis. In the world of transaction processing systems, more demands are made of information system than questions asked of the data. The occasional queries are typically limited to locating a particular record in the information system and preparing it for updates, or performing simple aggregations.

Decision-makers, on the other hand, generate a breed of questions unlike those geared to transaction processing. Such queries originate from the business need to analyze and process data in order to draw conclusions. These questions are usually complex and typically cover dimensions not relevant to OLTP systems, such as time period, product families or region of the world (Adriaans and Zantinge 1996). As a data warehouse is only applicable to a decision-support system environment, it is of little use to a firm that has a lack of integration in its operational environment. Although the transactional data provide the backbone for operational processing, they are fragmented since they were previously built separately from each other. An attempt can be made to integrate operational applications by producing data and process models that show the complete information flow requirements of the organization.

5 Types of data in the data warehouse

One can think of the data warehouse as a collection of historical transactions and summarization. It may also be thought of as a giant spreadsheet that sits on a big computer. The data warehouse holds different flavors of data. The following represents a common sampling of the type of data contained in the data warehouse (Corey *et al.* 1998).

- Transaction downloads from operational systems that are time-stamped to form historical records.
- Dimensional support data (client, suppliers, materials, equipment, human resources time, cost, techniques that worked etc.).

- Table to supports the joining of dimensional data and numeric facts relating to this data.
- Summarization of transactions (e.g., daily production by departments). These are in actual facts preemptive queries; the data are aggregated when it is added to the data warehouse rather than when a user requests for it.
- Miscellaneous coding data.
- Metadata that represents data about the data. This category might include sources of the warehouse data, replication rules, rollup categories and rules, availability of summarization, security and controls, purge criteria, logical and physical data mapping.
- Event data sourced from outside services, such as demographic information collated into the geographic areas in which a company operates.

6 Operational database versus data warehouse design

Operational system design and creating databases to serve operational purposes differ significantly from the goals of data warehouse design as we discussed in earlier sections. When creating a database for an online operational system in a relational model, the concern is with quick response time and efficient data storage and therefore the data model created must be in the third or higher normal form (Atre 1980). The process of normalization or arranging data in "normal" forms involves creating "relations" or tables in order to make the tasks of data maintenance (such as adding, deleting, updating and retrieving) less complex and more systematic. As data are moved from operational systems into the warehouse, they go through a process known as systematic denormalization that violates all the rules relational database architectures apply when modeling most systems. Systematic denormalization is carried out to enhance the performance of the warehouse by reducing *join* (an SQL operator) operations that are resource intensive. Compared to single table statements, *join* operations have the following characteristics (Corey *et al.*1998):

- Consume significantly more CPU;
- Require more temporary work space (on disk and in memory) for sorting;
- Require temporary tables for holding of intermediate results;
- Perform I/O since at least one I/O is required per table in the query

Ironically, when implemented, a data warehouse will assume expansive sizes, does not necessitate dynamic updates, and is used primarily for analytical rather than repetitive processes. Hence, normalization is not only futile but is in fact counterproductive towards factors like performance and ease of use when it comes to decision-support applications. The numerous *join* processes generated between normally distributed tables causes slow and cryptic query systems (SQL or Structured Query Language-based) with non-instinctive application logic for data warehouse users. The "Nested Relational Model" is presented as a possible solution to this problem by limiting database operations within predefined modules (Inmon 1992b).

7 Data architecture perspective of data warehousing

In this section, we will look at the components that constitute the data warehouse, a data architecture perspective and information flow process in a typical data-warehousing environment. The data warehouse database is a combination of many different components, including the following (Corey *et al.* 1998):

- Operational data source
- The staging area
- The data warehouse
- The subject data marts
- OLAP Server(s)
- Reporting tools
- Metadata repository
- Monitoring and administration of the warehouse.

A typical data warehouse architecture is shown in Fig. 1.

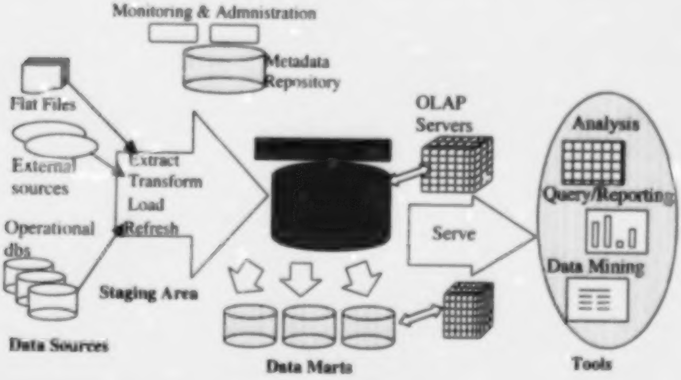

Fig. 1: A typical data warehousing environment architecture (Chaudhuri and Dayal 1996)

Thus an effective data warehouse should include tools for:

- extracting data from multiple operational databases and external sources;
- cleaning, transforming and integrating this data;
- loading data into the data warehouse; and
- periodically refreshing the warehouse to reflect updates at the sources and to purge data from the warehouse, perhaps onto slower archival storage.

The data are initially extracted from the source such as operational data or flat files, through the staging area, and then loaded into a data warehouse using various third party loaders such as "SQL* Loader" and data warehouse loading tools. The warehouse is then used to populate the various process-oriented data marts and OLAP servers, as illustrated in Fig. 1. The entire data warehouse then forms an integrated system that can serve the decision-maker reporting and analysis requirements of the user community (Chaudhuri and Dayal 1996).

The staging area is a set of database tables that will be used to receive data from the operational data source. This accelerates the manipulation of the data in the relational database in the operational environment and the loading into the data warehouse. The data structure in the data warehouse simplifies the enterprise's data while still retaining a non-process oriented database structure. In addition to the main warehouse, there may be several departmental data marts. Data in the warehouse and data marts are stored and managed by one or more warehouse servers (OLAP servers), which present multidimensional views of data to a variety of front end tools, namely, query tools, report writers, analysis tools, and data mining tools. Finally, there is a repository for storing and managing Metadata, and tools for monitoring and administering the warehousing system. (Inmon 1992a; Chaudhuri and Dayal 1997)

8 Data warehousing and construction information management

Normally the operational database is the central storage area of all the data needed to serve each business function of the entire organization. Today, many construction organizations are moving toward the new technology offered by client/server architecture to centralize their database at one location and decentralize their decision-making initiatives. In a typical construction management information system the database is essentially normalized to shrink the overall database size, thereby easing updates, and establishing program/data independence. As a result they are not able to support online analytic processing for strategic decision-making.

Incorporation of *historical, projected* and *derived* data is an important process in the implementation of data warehousing solutions in any construction organization. Historical data are most often compiled from existing operational data; projected information usually comes from spread sheets or external data feeds and derived data is computed by OLAP (online analytic processing) server's calculation engine. By integrating all three types of data, construction professionals will be able to support an operationally oriented decision-making process that looks forward as opposed to a system that reports only what has happened in the past. Support for historical data alone limits an operational system to only *what-happened* questions. Support for projected and derived data enables a system to additionally support *what-if* and *what-next* analyses. The ability of an OLAP server to deliver historical, projected and derived data all side-by-side creates forward-looking applications that provide significant value to end users that are otherwise impossible to deploy.

In a typical construction organization, the data will be gathered from vast amount of valuable information contained in operational sources such as accounting payroll, cost estimates, company and project finance, material inventory, equipment inventory, human resource data, and contract data. These data will then be transformed into a single, integrated, subject-oriented database. Project engineers, architects, suppliers, construction managers and all personnel involved in a construction venture, can then query and analyze the information in the warehouse to support business decisions in ways that were not possible before. A typical construction data warehouse will contain a large volume of historical data that will support more strategic decision-support needs such as long-term trend analysis in project cost, project duration, tender quotations, and experience derived from past projects. Building managers, for example, can compare alternative sites, building types, design and construction schedules and possible types of tenants or buyers in a local real estate market and be able to project expenditure and income streams to enable them to develop a more precise discount cash flow.

9 Overall benefits of implementing data warehousing in a construction organization

The overall benefit of data warehousing in any construction organization, in the view of the authors, will be to serve as a distinct centralized repository for online transaction processing systems in the organization. This data may contain extracts of vital business data from a variety of corporate databases, which can be analyzed and used as a strategic, competitive weapon. Successful data warehouse implementation in a construction organization will increase the productivity of construction managers, project developers, and the organization as whole. The inherent flexibility of online analytic processing (OLAP) systems means business users of OLAP applications can become more self-sufficient (Roussopoulos 1995). Managers are no longer going to depend on information technologists to make schema changes to create *joins*. Perhaps more importantly, data warehouse capabilities will enable managers to model problems that would be impossible to model using less flexible systems with lengthy and inconsistent response times. More control and timely access to strategic information both equal more effective decision-making.

Considering the fact that the construction industry is rapidly becoming a global industry, it is expected that many construction organizations are going to commit their effort to achieve tremendous benefits by implementing data warehousing technology in their organizations. The reasons for this are not far fetched from the numerous advantages inherent in data warehousing technology discussed in this paper. These benefits can more than compensate for the investment made in the implementation of a workable data warehouse.

Construction organizations will be able to compete overcoming barriers of time and distance and learn from the past, adjust to the present, and position for the future. For optimally utilizing the concept of data warehousing, however, fundamental differences between conventional databases and data warehouse such as current vs. historical data, large volume vs. very large volume data, and mission critical vs. decision-support applications must be understood. Rather than immediately adopting Relational Database Management Systems (RDBMS) for transaction-based, as well as information-based applications; it is recommended that DBMS (Database

Management System) are selected for the former whereas DWMS (Data Warehouse Management System) are chosen for the latter (The Data Warehouse 1998).

10 Organizational issues

Data warehouse developmental efforts, including attempts for improvements and changes, mandates considerations of how data warehousing will be supported in the construction organization. There will be the need for specific decisions regarding who will maintain the database, networks, third party OLAP tools and programming as well as any other decentralized applications. Because the effectiveness of data warehouse depends on the willingness of users to share data, this coordination can be difficult. Traditionally, this type of responsibility rests with the data processing or information system (IS) entity within the organization. For success of data warehousing in a construction organization the administration function must be separated into a new unit that has authority across the entire organization. In any of this organizational structure, the enterprise nature of data warehousing requires that stakeholders be integrated into the functional system. A typical approach currently used in most organizations practicing data warehousing is to create a data warehouse coordinating group represented by all the various units of the organization (Kimball and Strehlo 1995).

Despite the convincing potential of data warehousing in construction information management, the decision to invest in this direction must be done with care since data warehousing is not always the most cost-effective or even the best solution for an organization. It may sometimes be advisable to start by building summarized reporting structure in the OLTP database. These structures can eventually be ported to the warehouse. Prior to any system development effort, it is also important to undertake careful financial analysis in terms of cost and benefits to determine the viability of the proposed investment in data warehousing. The costs are straightforward to estimate in a data warehousing environment as in any online transaction processing environment, however benefits are far less tangible because in most cases the exact target audience of the system is rarely known. In general, the decision to implement a data warehouse should be based on the following questions (Corey *et al*. 1998):

- Does it give us competitive advantage?
- Does it improve the bottom line?
- Will it deliver on all its promises?
- Will it deliver on time?
- What will be the risk if it is not implemented?
- What will be the risk if it is implemented?
- Will it deliver on budget?

It must be emphasized that while it is important to discuss the benefits of a planned warehouse, it is usually impossible to quantify these benefits in dollar terms. In many organizations that are currently practicing data warehousing technology, the decision to construct the warehouse is frequently an act of faith.

11 Conclusion

Most construction organizations have accumulated vast amounts of data over the years through the normal daily transaction processing activities. These databases have, in most cases, not been designed to store historical data or respond to queries except to support all the applications used in the organization. Data warehouse represents another type of database, solely designed to support strategic decision that can be set up in any construction organization. Data warehousing technology can enable construction companies to consolidate information from diverse operational systems into one source for consistent and reliable information. This will give construction project managers the opportunity to bring wisdom and insight into their decision-making process.

The premise of data warehousing, as presented in this paper, is to make large amount of information available to large community of end users in an organization. Presumably, the more users that are able to access data warehousing applications, the more value will be provided to the organization by the data warehouse. This implies that to maximize success, the online analytic processing (OLAP) server in the data warehouse must be made accessible to a wide variety of end-user tools (OLAP 1998). As a data warehouse stores sensitive business information in a centralized location, the importance of data security and user management cannot be overemphasized.

While many commercial products and services exist, there are still several interesting avenues for research in order to adopt the most appropriate technique and customization to suite the needs of individual construction organizations. By providing the ability to model real business problems and more efficient use of people resources, data warehousing can provide the means for construction organizations to respond more quickly to market demands. Market responsiveness in turn often will yield improved revenue and profitability. A good data warehouse should provide the right data to the right people at the right time (DISC 1997) – which is the main purpose of any organizational information system.

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231 SLAB FORMWORK DESIGN USING GENETIC ALGORITHM

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Abstract

A method to design cost-optimum slab formwork components is proposed in this paper. Genetic Algorithms (GAs), a technique based on the principles of natural selection and evolution, is applied to solve the optimisation problem. GAs search from a population of possible solutions limited by a set of constraints. The cost of form components and labor involved, were considered for the formulation of the objective function of the optimisation problem. The bending moment, shear, maximum deflection, imposed ACI code provisions, etc., were used as constraints for the optimisation problem. Application of GA to the formwork design problem provides optimum design parameters such as the optimum cross section for form members, optimum spacing of form members, etc., while minimising the total cost. Formwork made either from wood, wood-metal composite or metal alone can be designed using the proposed technique. The paper presents the case of general formwork design, however, the method as a whole readily applies to the design of formwok for elevated slabs and high rise concrete elements.

Keywords: Formwork design, genetic algorithm, optimisation, construction cost

1 Introduction

Slab formwork holds and provides support for freshly placed concrete through a framework of sheathing, joists, stringers and shores (Fig. 1). Sheathing is in the form of sheets of plywood, while joists, stringers and shores act like beams and columns. Sheathing retains both the concrete and applied loads while supporting the members comprising of joists, stringers and shores, which holds the sheathing in place. Joists and stringers act horizontally while shores act vertically. Stringers are supported on shores while joists are supported on

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The essential requirements for good formwork are quality, safety and economy (Speigel & Limbrummer, 1992). Formwork should be designed accurately, erected and kept rigid and tightly jointed with proper finish. Economy requires the form to be simple, easy to handle, standardised and reusable. Safety requires the formwork to be strong and sound, as formwork failure is a major cause for accidents during construction.

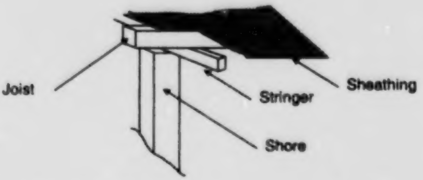

Fig. 1: Parts of a typical slab formwork

The formwork labor and material cost is estimated to be approximately 30% of the concrete slab cost (Senousi & Ansari, 1996) as shown in Fig. 2. The formwork material cost accounts for about 12% of the total formcost (Hanna & Senousi, 1997). Minimising the formwork cost helps to reduce the overall construction cost. In this research, a genetic-algorithm-based optimisation technique is proposed to design the optimum section of joist, stringer and shore along with their spacing.

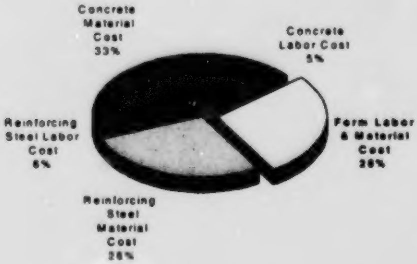

Fig. 2: Typical cost breakdown for concrete slabs

Traditionally slab forms are designed based on developed design tables, taking into consideration the strength of forms to resist the failure and stiffness to avoid deflection. Christian (1987) proposed an integrated microcomputer package for formwork design based on published data obtained from empirical guidelines and recommendations given in Hover (1981) and Peurifoy (1976). Ringwald (1985) proposed a set of design curves for specific wood type, for which safe formwork design values namely size and spacing of members can be inferred while Senousi and Al-Ansari (1996) proposed a computer program for the design of slab formwork components. In these works, the design process does not evaluate all possible solutions to find an optimum formwork design while some of them are even based on empirical grounds. Selecting the sizes and spacing of form members empirically can be very unsatisfactory, uneconomic, and even dangerous. Any under-designing can result in ultimate failure of the forms while over-designing can result in excessive cost. Further, selecting one of the near optimum solutions might not give the complete cost advantage required, as there can be a precise optimum design combination (size and spacing) available somewhere in the solution space.

An Artificial Intelligence (AI) based optimisation procedure to design the formwork components is introduced in this paper. The cost for each of the form components is minimised while maintaining the safety of the formwork. Using this formulation, an optimal solution is evolved by the Genetic Algorithm from a set of points limited by the given constraints.

2 Formwork

Design of construction formwork involves a step-by-step analysis of sheathing and framing members. The sequence of these design steps depends in large measure on the overall plan of the job. Formulas for shear, bending moment and deflection are traditionally used in designing and limiting the spacing of form members. Design should be such that the formwork should support all the loads applied on it without excessive deflection or collapse leading to accidents. A typical structural formwork system that supports the freshly placed concrete for an elevated slab construction is as shown in Figure 1. The procedure used in this paper for the formwork design is based on the standard equations available for structural design contained in the ACI formwork standard, explained further by Hurd (1989).

2.1 Load on the form members

Loads applied on the forms are of two categories: (a) Vertical loads such as the weight of the concrete, the reinforcing steel, the forms themselves as well as the construction live loads, and (b) lateral loads including the externally applied loads and the internally applied loads. The current formwork design specifications are based on allowable stresses developed due to these loads, as specified by Hurd (1989).

Form members are designed to bear the effects of imposed loads. Major slab formwork loads include dead load, live load, wind load and equipment impact load. Normally, weight of ordinary concrete including the reinforcement is taken as 150 lb/ft^3. Weight of formwork usually comes to about 3 - 15 psf which is usually neglected. Live load comprises of the weight of workmen, construction equipment and storage materials along with impact load of 50 psf. Recently, Karshenas and Heinrich (1994) performed an investigation on the impact loads associated with the crane-and-bucket method of concrete placement. They show that, for bigger slabs (30 cm or thicker), designing the formwork for the weight of slab plus 50 psf of impact load is not very safe where the effective impact load is higher than the design loads specified by ACI 347R-88. Pouring $1.5m^3$ (2 cu yd) of concrete from 1.5 m height is an extreme situation, but according to a number of field superintendents, it is a probable event. For slab thickness less than 30 cm, (e.g., 20 cm, 12.5 cm, etc.) 50 psf is found to be within the range of design loads specified by ACI 347R-88. For the current problem, 50 psf live load based on a fairly conservative estimate of likely field situations is adopted as an example. A potential user can modify these design limits according to their standards without affecting the optimisation process. Loads in this study are defined as follows:

$$\text{Design load} = \text{Dead load} + \text{Live load} \qquad (1)$$

$$\text{Dead load of concrete and steel} = \frac{t}{12} \times 150 \text{ psf} \qquad (2)$$

where "t" is the thickness of the slab.

Neglecting the weight of forms, and taking minimum recommended live load as 50 psf, the total load $= \frac{t}{12} \times 150 + 50$ psf (3)

2.2 Stress on form members

Bending members like sheathing, joists and stringers, are considered as uniformly loaded and supported on three or more spans. They are analysed for bending moment, shear and deflection. Shoring is analysed for compressive loads and also for the bearing stresses developed at supports. The traditional stress equations as specified by Hurd (1989) are used for the formulation of constraints.

Wood has the property of being able to support excessive loads for short periods of time. So normal allowable stresses can be increased by 25% as formworks are temporary structures and the loads are of short duration. Further the loads reach a peak during pouring activity and rapidly fall off as concrete hardens. Partially seasoned wood is normally used for the sheathing. Partially seasoned wood has a moisture content of more than 19% and hence allowable stresses must be decreased by a factor of 0.86 for bending, 0.97 for horizontal shear and modulus of elasticity.

3 Design methodology

In a beam subjected to a uniformly distributed load (w) (lb/ft), expressions can be derived for the maximum allowable span length by equating the allowable unit stresses to the maximum unit stresses developed. The moment expressions are for maximum positive or negative moment. The limiting deflection is normally taken as 1/360th of the Allowable Span (*l*) (Hurd, 1989).

For a beam uniformly loaded and continuous over three or more spans, the following expressions are used for the design:

$$\text{Max bending moment (M)} = \frac{wl^2}{120} \qquad (4)$$

$$\text{Resisting bending moment (M)} = f \times S \qquad (5)$$

where, f = calculated unit stress in bending (psi), w = uniform load (lb/ft),
S = section modulus (in^3),
M = maximum bending moment (in.-lb.), and *l* = spacing

From (1) through (5),

$$\text{Maximum spacing (l)} = 10.95\sqrt{\frac{fS}{w}} \tag{6}$$

$$\text{Calculated unit Shear stress (H)} = \frac{1.5V}{A} \tag{7}$$

$$\text{Max horizontal shear (V)} = 0.6wl \tag{8}$$

From (7) and (8),

$$\text{Maximum spacing } (l) = \frac{Hbh}{0.9w} \tag{9}$$

Neglecting loads within a distance (h) from supports,

$$\text{Calculated unit Shear stress (H)} = \frac{0.9w}{bh}\left(1 - \frac{2h}{12}\right) \tag{10}$$

$$\text{Max horizontal shear (V)} = 0.6w\left(1 - \frac{2h}{12}\right) \tag{11}$$

From (10) and (11),

$$\text{Maximum spacing } (l) = 12\left(\frac{Hbh}{0.9w} + \frac{2h}{12}\right) \tag{12}$$

Where, V = maximum shear (lb), H = calculated unit stress in shear (psi),
b = width of form member, h = breadth of form member

Forms must be designed so that the members will not deflect beyond certain maximum values to avoid the formation of bulges and cracks. Deflection is a governing factor where the depth of the member is relatively small compared to its span. Hence for sheathing, deflection will be the governing factor while for joists and stingers the bending and shear are often the governing factors.

$$\text{Deflection} = \frac{w}{12} \times \frac{l^4}{145EI} \tag{13}$$

$$\text{Allowable deflection} = l/360 \tag{14}$$

from Eq. (13) and Eq. (14),

$$\text{Maximum allowable span } (l) = 1.69\sqrt[3]{\frac{EI}{w}} \tag{15}$$

Where, E = modulus of elasticity (psi), I = moment of inertia (in^4)

Compression (both parallel and perpendicular to the grain) = $f_{comp} = \frac{P}{A}$; where, f_{comp} = calculated unit stress in compression (parallel or perpendicular to the grain) (psi), P = concentrated load (lb.), and A = cross-sectional area (in^2).

Consider a strip of sheathing of the specified thickness and 12 inch in width for this illustration. Based on Eq. (1) through Eq. (15), the allowable joist spacing based on bending stress, shear, and deflection consideration can be computed. The lowest of the computed values will finally determine the maximum spacing of the joists. Once the spacing is computed, the required quantity of each form member can be obtained. It should be noted that for the joist design, the values of f, S, E, and I in Eq (3 to 15) are the values that correspond to the sheathing material. Extreme fibre bending values were scaled by a factor 0.86, to account for the moisture content and by 1.25 for load duration consideration for this illustration. Douglas Fir Leech Lumber is assumed to be used for the form members and the corresponding extreme fibre bending value was used for the design computation.

Based on the computed joist spacing, the joist itself is analysed to determine its maximum allowable span. Joists are assumed to be continuous over three or more spans. Each joist must support the load from the sheathing halfway over to the adjacent joist on either side. Therefore the width of the load carried by the joist is equal to the spacing of the joists. The selected joist span becomes the spacing of the stringers. Based on the obtained stringer spacing, the process is repeated to determine the maximum stringer span which is the distance between the vertical supports (shores). Joist loads will be acting on the stringer as a series of concentrated loads but for the sake of simplicity the load is treated as a uniformly distributed load. Once the distance between the vertical supports (shores) is obtained, the load to be carried by each shore should be less than the safe working load available for the shores which can be calculated as the product of shore spacing, stringer spacing, and design load. A steel shore was assumed for this illustration.

3.1 Check for bearing stresses

The bearing stresses produced when one member rests upon another are critical in the design of formwork. The members must have sufficient area of bearing on their supports to prevent crushing of the grain. Otherwise the formwork will settle out of position or have undesirable cracks and openings. These stresses need to be analysed wherever joists rest on stringers, and where stringers rest on shores. The bearing forces applied to the horizontal timber member cause compression perpendicular to grain. The allowable stresses for compression perpendicular to the grain are lower than those for compression parallel to grain. The calculated stringer span is checked against the capacity of the shores used to support the stringers. The load on each shore is computed as the product of shore spacing and the load per foot of the stringer. Thus the maximum shore spacing is limited to the lower span length as governed by the stringer strength or shore strength. Stringer bearing on shore also should be kept below the short term compression perpendicular to grain. Stringer bearing on shore is computed as the ratio between the total load on shore to the bearing area.

It is also necessary to check the bearing at the point where each joist rests on the stringer. This is done by comparing the resulting stress with the allowable unit stress in compression perpendicular to grain. Joist bearing on stringer should be kept below the short-term compression perpendicular to grain. Joist bearing on stringer is computed as the ratio between the total stringer load to the corresponding bearing area.

4 Genetic algorithm

Genetic algorithms (GAs) is a computerised search method based on the ideas of genetics and natural selection proposed by Holland (1975). They use random techniques but exploit information from the past experience to evolve solutions to real world problems, once they are appropriately encoded. GAs have been demonstrated to be robust heuristic search techniques that are capable of rapid identification of optimal design options whilst avoiding convergence on local optima. Even though GAs are not guaranteed to find the global optimum solution to a problem within finite time, they are generally proved valuable at finding near optimal solutions to problems that were previously considered too large or complicated to solve within reasonable amount of time. This adaptive search technique, which has powerful non-linear processing capabilities, can be used for solving multi-dimensional optimisation problems with discrete variables and discontinuous functions. However GAs are computationally expensive and will usually be outperformed when specialised algorithms for a problem exist.

GAs work with a population of individuals each representing a possible solution to a given problem. Each candidate solution is represented as a string of bits (a set of binary/character strings) analogous to chromosomes and genes in evolution theory. GAs assign a fitness score to each individual based on the quality of the solution it represents and highly fit individuals are reproduced by breeding with other individuals. New populations are continuously evolved over generations. During the evolution process the quality of the population increases, hopefully leading to an optimal solution. Finally the population will converge to an optimal solution to the coded problem.

A fitness function is necessary for each problem to be solved by GAs. Fitness is determined by an objective function or subjective judgement. Objective function provides a measure of performance with respect to a particular set of parameters. Fitness function transforms that measure of performance into an allocation of reproductive opportunities. Fitness function is generally used to map individual bit strings into a positive number which is called the individual's fitness. Probability that an individual in the current population is propagated to the future generation is proportional to its fitness. Survival-of-the fittest method adopted by GA selects new strings from the old population randomly, but biased by their fitness.

Reproduction operators of GAs provides a means to weed out the bad and to generate new and better set of solutions during every iteration. Desirable characteristics of the parents are inherited by off springs during the reproduction phase by combining the best characteristics of both parents. The main reproductive operators are: (a) selection, (b) crossover, and (c) mutation. In the selection phase, individuals are selected from the population and recombined to generate new offspring. The objective of selection procedure is to give exponentially increasing trials to the fittest individuals; thereby, less fit individuals are eradicated and individuals of higher quality are selected and rewarded by letting them reproduce more often. Crossover is a reproduction process by which the bit-strings of two fit parent individuals combine to produce two child individuals. Single point crossover is usually performed by swapping the fragments between two parents at a random point along the bit string.

Crossover is generally applied to randomly paired strings with a moderate to high probability denoted P_c(usually the value of P_c falls between 0.6 and 1). Mutation is another reproductive operator that provides a theoretical guarantee that no bit value is ever permanently fixed in all strings. Mutation introduces random modifications and hence induces a random walk through the search space. During mutation, a portion of the new individuals will be flipped to generate a new bit. This is a critical operator that prevents the GAs from being stuck at good but non-optimal solutions. Mutation is done with a low probability denoted by P_m (usually applied with less than 1% probability). Mutation helps to maintain diversity within population and restrain any premature convergence.

The first generation in the GA process is a population of randomly generated individuals. From there on, the genetic operations, in concert with the fitness measure, operate to improve the initial population. Fig. 3 shows the steps involved in a typical GA implementation. Introduction to GA can be found in Austin (1990), Beasley et. al (1993) and Whitley (1993). Tabtabai and Alex (1997, 1998a 1998b 1998c and 1999) present the utility of GA to various construction management optimisation problems.

5 Formwork optimisation procedure using genetic algorithm

The formulation and solution procedures adopted for the formwork optimisation problem in this paper, have the following major steps:

a) Identify the solution structure of the optimisation problem,
b) Code the solution in the form of strings,
c) Define the objective function to be optimised,
d) Define the GA operators and stopping criteria,
e) Evolve solutions until the stopping criteria are met, and
f) Decode the evolved solution strings into the optimum solution.

Figure 3 illustrates the complete GA application methodology, which is analogous to the evolution strategy found in nature.

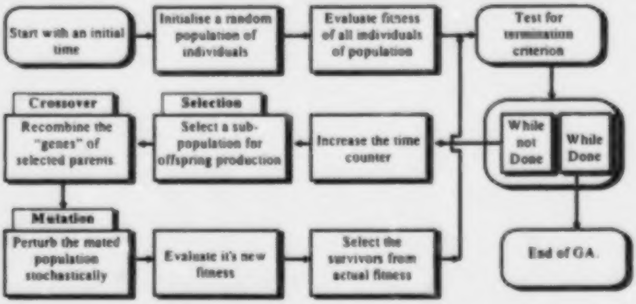
Start with an initial time
Initialise a random population of individuals
Evaluate fitness of all individuals of population
Test for termination criterion
Crossover
Recombine the "genes" of selected parents
Selection
Select a sub-population for offspring production
Increase the time counter
While not Done
While Done
Mutation
Perturb the mated population stochastically
Evaluate it's new fitness
Select the survivors from actual fitness
End of GA

Fig. 3: A typical genetic algorithm optimization process

The objective function for the optimisation problem can be formulated as:

$C = N_1 \times C_1 + N_2 \times C_2 + N_3 \times C_3 + N_4 \times C_4 + A \times t \times C_5$ (16)

in which,

N1= No. of sheathing,	C1 = Unit cost of sheathing,
N2 = No. of joist,	C2 = Unit cost of joist,
N3 = No. of stringers,	C3 = Unit cost of stringers,
N4 = No. of shores,	C4 = Unit cost of shores,
A = Area of slab,	C5= Unit labor cost for unit volume of concrete
t = thickness of slab	

5.1 Implementation

The values for GA control parameters, namely probability of crossover (P_c), probability of mutation (P_m) and number of generations (N_{gen}), were selected based on values reported by other researchers in various optimisation problems. The elitist strategy, which always allows the best string in each generation to survive in the next generation, is employed. GA implementation was performed using GeneHunter™, a commercially available genetic algorithm add-on software from Ward System, Inc., for the Microsoft Excel™ spreadsheet. A microcomputer (IBM compatible Pentium-class, 16 MB Ram, 100 MHz machine), was chosen as the hardware platform to run the evolution process outlined in Fig. 3. This set-up was found to be simple, adequately efficient, and cost effective. Moreover, microcomputers of above minimum configuration are commonly available in most medium to large construction offices.

The design problem is first represented in the spreadsheet. The inputs required from the designer are first represented under various sections namely:

- structural inputs (length of slab (m), thickness of slab (cm), breadth of slab (m)),
- sheathing inputs (sheathing thickness (mm), sheathing width (breadth) (m), sheathing length (m), bending stress (MPa), young's modulus (GPa), shear stress (MPa)),
- joist & stringer inputs (bending stress (MPa), young's modulus (GPa), shear stress (MPa), compression perpendicular to the grain (MPa)), and
- shore inputs (bending stress (MPa), young's modulus (GPa), shear stress (MPa), end plate dimensions (cm), shore capacity (KN)).

Individual cells are designated for the entry of these input variables. Once the input variables are specified in the spreadsheet, a new set of cells are designated for the output variables, namely the breadth of joist, height of joist, breadth of stringer, and height of stringer measured in appropriate units. During the optimisation process, GA considers a set of joist and stringer sizes for each iteration. The evolved shore and stringer sizes are used to compute the allowable spacing using Eq (6), Eq (12), and Eq (15). The minimum of this value is then selected as the spacing for members. The spacing of shore, stringer, and joist are limited by considering the stringer bearing on shore, joist bearing on stringer, and load carrying capacity of each shore. The load carrying capacity of steel shore is assumed as 22.2KN. The expected reuse was taken as 3 for sheathing, joist and stringer and 25 for the steel shores as practised in the local industry. The number of reuses can be judged based on the care exerted by the form handlers during the dismantling, erecting and storage of formwork. The type of form components, unit material costs, unit labor costs, and the potential reuses of the slab form components were assumed in this problem.

During successive evolution, GA attempts to evolve the optimum dimensions for these members that will eventually result in minimum total cost. For this example, a population of 100 individual solutions has been considered during each evolution. From the initial population the worst solutions were discarded while the best solutions were combined with each other by crossover, thus creating a new population. The probability of crossover used for the problem was 0.9 ($P_c = 0.9$). A 1-point crossover was used for the current problem. Occasionally a gene will be altered to produce a mutation. The probability of mutation adopted for the current problem was 0.01 ($P_m = 0.01$). Fitness of the current population was determined by the GA and the above steps were repeated on the current population until the subsequent adaptation created a more fit solution. The entire genetic algorithm process continues through many generations until the best solution is good enough to become the required solution decided based on the iteration time and the rate of change of objective function.

The total cost of the formwork was derived from the number and spacing of each individual formwork component used for the construction of the facility. Optimisation process using GA was carried out for various slab sizes. The material properties of each component, the unit cost of each component, deflection limits, and the slab dimensions were required to be input by the user. During the evolution process, the GA evaluates different dimensions of each formwork component, which will satisfy the design constraints, till the combination that gives the minimum cost is reached. Different sizes of joists and stringers have been evaluated by the program to find out the optimum dimensions resulting in overall minimum formwork cost.

For a standard slab carrying standard load with thickness ranging from 10 cm to 15 cm, based on the constrains set, GA yields an optimum section of 5 cm by 5 cm joist and 5 cm by 20 cm stringer. For a slab thickness of 10 cm, 45 cm spacing is found to be adequate for the joist, while stringer and the shore need to be spaced at 58 cm and 220 cm respectively. With the increase in the thickness of slab to 15 cm, the dead load of slab increases and the spacing becomes 43 cm., 55 cm., and 210 cm, for the joist, stringer and shore respectively. When the slab size increases, the joist size remains the same but the stringer size varied to 5 cm by 20 cm. The spacing for the 10 cm thick slabs are 45 cm for joist, 60 cm for stringer, and 200 cm for shores. For the slab of thickness of 15 cm the joist and stringer spacing remains the same but the shore spacing decreases to 190 cm. The computed formwork design parameters were found to be safe and economical. The above problem was presented as an illustration about the use of GA for formwork design. However, a comparison between the design options based on traditional methods and use of practical design constraints will provide more confidence in these results.

6 Summary

The formwork should be designed such that the system is both safe and economical. Improper formwork design is one of the major causes of concrete construction failure. In the traditional formwork design procedure, the section is kept constant by the designer and the spacing is calculated based on bending, shear and deflection limits without specific consideration to the involved cost. The spacing that satisfy the constraints are considered acceptable, which might not necessarily give the optimum minimum cost. A new approach to design the concrete slab formwork using Genetic Algorithm is proposed in this paper. The objective is to design the formwork in a most economical way with maximum functionality.

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232 MANAGING AND EXPLOITING KNOWLEDGE ASSETS IN THE CONSTRUCTION INDUSTRY

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Abstract

This paper reviews knowledge-based and decision support techniques in the construction industry with a view to highlighting how construction organisations can exploit knowledge as an asset. It introduces Knowledge Management and Decision Support Techniques and provides information on example applications that demonstrate their use in construction and non-construction sectors. Guidelines for deciding on the suitability of knowledge-based techniques for solving a given problem are provided.

Keywords: artificial intelligence, decision support, integrated systems, intelligent systems, knowledge-based systems

1 Introduction

The success of a construction business in today's competitive market place depends critically on the quality of the knowledge it possesses regarding its markets, products, and technologies. To maintain and improve competitiveness, it is essential to identify, plan, and control knowledge assets with the same priority currently afforded to traditional tangible assets. *Knowledge Management* (KM) techniques offer strategies for identifying and exploiting knowledge assets. *Knowledge-based* (KB) and *Decision Support* (DS) techniques complement knowledge management by enabling the storage of knowledge assets in computer-based systems that can then be used to assist decision making. The recent UK Department of Trade and Industry Intelligent Systems in Business Programme (DTI, 1998) identified the following

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benefits in a range of industrial sectors resulting from the application of Knowledge Management and Knowledge Based techniques:

- **Organizational Memory** - preservation of knowledge when staff move.
- **Decision Support** - assisting experts by evaluating and suggesting possible options, enabling a wider range of design solutions etc. to be considered
- **Routine Decision Automation** - relieving key staff from trivial but time consuming tasks.
- **Product Improvement** – enabling increased differentiation from competitors' products through the addition of smart features.

Although KB techniques can be applied to create stand-alone applications they may well be more effective when implemented as part of a wider system accessible throughout the organisation or the project team via networks. Encoding business processes and decision paths in company or project Intra/Extra-nets can provide additional advantages in facilitating Quality Assurance (QA) and recording experience for future re-use. The rapid uptake of such networks and the huge increase in computer processing power and availability, make it important to review this technology at this time.

This paper examines how businesses in the construction industry can obtain the benefits outlined above by embarking on a knowledge management programme. It overviews knowledge management and decision support techniques, provides case-studies to demonstrate their benefits, and recommends steps that a construction business can take now to start realising these benefits.

This paper was authored by The Network of Experts in Knowledge Based Systems hosted by BRE and funded by the UK Government's Department of the Environment, Transport and the Regions (DETR). The Network brought together around one hundred and fifty members from Industry and Academia to assess the Knowledge Management requirements of the construction industry and identify appropriate techniques and tools. The network's Web Site provides complete details of its activities (http://helios.bre.co.uk/kbs/).

2 Overview of knowledge management and decision support techniques

Knowledge management is not a new gimmick. It is common sense. Knowledge can be an organisation's greatest asset. It depends more on the number of connections linking the information rather than on the amount of information (Macintosh, Filby, Kingston & Tate. 1998).

Knowledge management deals with the intangible nature of intellect. It involves much more than technology. We need to understand: what we need to know, where insight and knowledge gets created, how we can best capture it, how it can get us to our destination. (Koulopoulos, 1996)

A conclusion made by researchers in sustainable competitive advantage is that the only thing that gives an organisation a competitive edge is what it knows, how it uses what it knows, and how fast it can know something new.

2.1 Knowledge management

Knowledge management methods guide the identification and analysis of the knowledge used within an organisation and the establishment of a programme to ensure that this knowledge is preserved and developed. Knowledge management methods are generally taken to include the following stages:

- **Identify Your Knowledge Assets**: analyse the knowledge used in the operation of a business: e.g. technical know how, design products, information sent to customers, research and development results and patents, records of company procedures, operating guidelines, management expertise, marketing expertise
- **Document Your Knowledge Assets:** describe each asset in terms of its subject area, quality, and the time and places that it is available. An estimator's knowledge might be documented as follows: "The knowledge is used to generate cost estimates for the installation of wiring in buildings. It is based upon 10 years' experience and has proved accurate. This knowledge is held by an individual in the design department and is available during working hours."
- **Identify Knowledge Management Related Processes**: for each asset identify the processes for developing, updating, using, assessing, and transferring it. For the cost estimation example above, updating processes may include attendance at training courses; reviews of estimates after project completion. A transfer process might include the documentation of estimation best practice to enable other members of staff to perform this task.
- **Identify Opportunities for Developing Knowledge Assets:** issues with assets typically, e.g. bottlenecks, occur when demand upon an asset exceeds supply. In the estimator example, a bottleneck may occur when only one individual can perform this task.
- **Prepare Programme of Actions:** the opportunities for developing knowledge assets are best realised through a programme of focused actions. Knowledge Management methods guide the selection issues that are essential to a business. In the estimator example, relieving the bottleneck would only be recommended if this issue is holding the business back. Example actions include: securing the knowledge from an expert who is about to retire by documenting his knowledge, and sharing knowledge by forming a network of people working in that area.

Embarking on a knowledge management programme will result in new insights into the knowledge assets critical to the competitiveness of a business and the formulation of a course of actions to maintain and develop those assets. These benefits can be achieved through an investment in time for training in knowledge management methods and the time required to carry out the programme. The Knowledge-based and decision support techniques described in the next section increase the options available for managing assets, but do require some additional investment. The following section introduces these techniques by balancing the benefits they offer against the increased investment required to achieve them.

2.2 Knowledge based and decision support techniques

Knowledge-based and Decision Support techniques enable the storage of knowledge assets within computer systems that can then be used to assist decision-making. At their current level of maturity the techniques have been used to construct systems that possess human level competence over a narrow range of routine tasks. This maturity enables the development of effective decision support systems that in no way replace human decision-making. Rather, by complementing and supporting experts, the techniques offer the following benefits:

- **Addressing Knowledge Bottlenecks:** encoding an expert's knowledge within a decision support system provides wider access to that knowledge. This access enables people to initially pass requests through the decision support system to identify routine problems. Once resolved, the human expert can be used to fully check final requests. This frees the expert to spend more time identifying and resolving more complex problems.
- **Ensuring Knowledge Preservation:** when people are about to retire, their expertise can be captured within a decision support system. This allows others to make use of that expertise after the expert has left. Properly focused on the aspects that are essential to a business, this approach can ensure a tidy transition as other employees develop this expertise themselves.
- **Best Practice:** expertise from experts can be encoded within a decision support system to produce a best practice framework. This approach enables experts to exploit the knowledge of other experts when tackling a complex task.
- **Smart Features:** the use of the complex products supplied within the construction industry can require a high level of knowledge from the customer. Decision support systems offer an opportunity to supply products together with the knowledge required to deploy them. This can both reduce support requests from customers and provide a competitive differential between a business's products and those of its competitors.

Three main groups of techniques are available for building knowledge-based and decision support systems. Each is described below with the emphasis placed on the benefits and complexities of applying the techniques within the group:

- **Explicit Encoding of Knowledge:** these techniques provide a language for recording an expert's knowledge. An expert's knowledge is captured through questions, observations etc. and encoded in the language used by that particular technique. Knowledge acquisition methods and tools are available but require considerable effort. The explicit specification of knowledge enables the system to explain its conclusions.

- **Using Past Cases:** these techniques use records kept on solutions to similar problems to develop a solution to the case in hand. They require access to the design and costing of past projects. While they remove the need to capture expertise from experts, they are dependent upon the quality of information that is recorded on past work and on the similarity to current work.
- **Adaptive Systems**: these techniques entail learning how to solve problems by examining the situations given to experts and the responses they provide. They have proved effective at tackling fault detection problems. While their ability to learn by observation removes the need for a knowledge acquisition process, they cannot explain the conclusions that they reach.

Knowledge-based and decision support techniques complement knowledge management methods. They offer effective approaches to removing knowledge bottlenecks, preserving knowledge, encouraging best practice, and adding a competitive differential to products. AI techniques are now in very common usage but hidden as part of Word Processing packages, drawing tools etc.

The following section presents brief descriptions of actual applications to underline these potential benefits. Section 4 includes a checklist to assist in determining if a knowledge-based system is appropriate.

3 Examples of applications

3.1 Non-construction industry

Bid/ No bid Decision Support System - Each year *Short Brothers* receives many invitations to tender. Owing to the high cost of bidding, inquiries are evaluated and filtered by a Bid/ No bid committee. An intelligent system has been developed that uses a combination of weights derived from previous bids, and the encoded knowledge of several managers to evaluate proposals. The system has resulted in several benefits. It ensures consistent decision making, improves the rationale behind bidding, and speeds up the decision making process. The system has resulted in cost savings because of the speed up in the bid/no bid decision. This results in more time to spend on actual bids - thus increasing the company's bid-to-win ratio. It allows better proposals to be produced and improves allocation of bidding resources. Such a system could have considerable scope within the construction sector. (DTI, 1998).

Procurement - ***EXPERT PROVISIONER*** is a Knowledge Based System that supports Royal Air Force (RAF) Range Managers in the procurement of consumable supplies. The system consists of a graphical user interface to display the procurement item requisition information and a consultation style interface to a knowledge-based system. RAF Wyton houses the central supplies procurement centre for the RAF. 500 Range Managers are responsible for processing orders valued at over £1.2 billion. By linking into existing procurement information and providing a knowledge-based decision aid, Expert Provisioner allows the RAF to know exactly what has been bought, what it has cost and why it is needed. The aim is to reduce the uncertainty of procurement budgets near financial year-ends, wastage through over-ordering, taking advantage of price breaks for large orders and maintaining consistency of order processing. Expert Provisioner was successfully evaluated by end users and a full production system developed.

3.2 Construction industry applications

3.2.1 Bridge Fabrication error solution eXpert (BFX)

In bridge engineering, fabrication errors occur during the manufacture of elements of the steel assembly. These errors can have deleterious effects on the performance of a bridge if they are not repaired properly. Errors may cause delays in the fabrication process. In the past, Kansas Department of Transportation (KDOT) handled these bridge fabrication errors in a very non-scientific, non-procedural manner on an individual case-by-case basis. Only certain staff members with previous experience in handling these fabrication errors were able to provide repair solutions. The expertise within KDOT was also scattered or scarce, as engineers within different districts were familiar with different types of problems and repair solutions.

A rule based expert system, Bridge Fabrication error solution eXpert (BFX), was developed at the University of Kansas as a joint venture with KDOT. Its objective was to create an expert system for solving the fabrication errors that would provide a standard repair procedure for KDOT. Currently, the system is in operation at the bridge design offices of Kansas Department of Transportation. The system was completed and delivered to the KDOT in January 1994. Over 100 cases were acquired directly from fabrication shops, state inspectors' field notes, and bridge project documents. Of these cases, 77 were used to develop the expert system and 51 were used to validate the system. The 548 rules formulated for BFX's knowledge base were implemented in the expert system development package, Level 5 Object. BFX is capable of handling errors in the areas of tolerances, drilling and punching, cutting, and lamination. (Bocox J, Roddis WMK, 1996)

3.2.2 ELSIE

The ELSIE Expert System is a structured planning tool based on four modules: budget, time, procurement and development appraisal. It was first released in 1985 and runs on a PC, and hence on the machine used by most surveyors. It was initially developed at the University of Salford in an 18-month project funded by the Alvey Programme, after which a company was formed and continued development took place. ELSIE was built using the Savoir Expert System shell, which was selected for its efficiency and its inference net formalism. ELSIE's four modules are integrated around a project database so that information given in one module will be passed to others if required. All modules operate by asking the user a sequence of questions.

The knowledge base contained links that determine the dependencies among the pieces of information held, so that the answers given are propagated 'intelligently' throughout the knowledge base and may affect which questions are asked later on, or in which order. After the main question sequence, the result is declared and the user arrives at a 'What Now' point, at which explanation reports can be obtained, information can be over-ridden, and the information can be archived in the project database for later use. Not only may the answers to the question sequence be overridden but also upwards of a hundred assumptions that the module makes. In practice, the question & answer dialogue would be changed to perform what-if analyses, while the assumptions would be overridden to take account of special or local circumstances. The user interface is relatively simple, comprising 'windows' composed of character graphics. To certain questions the user may answer 'unknown', in which case the module makes an intelligent assumption (Basden, 1997)

3.2.3 Codes, Regulations, Document/ Product Retrieval

Knowledge based systems technologies can be used to capture knowledge about the structure of documents and the rationale behind information in documents. This was demonstrated in the ***PLINTH*** system developed by AIAI for the Building Directorate of the Scottish Office. The system facilitates the capture of the rationale behind the Building Standards Regulations for Scotland, in addition to the structure of technical documents. This structured knowledge assists the reader whilst navigating the complex interrelationships between sections. The technology may be applied to other types of structured document such as a building's design (Casson, 1992).

3.2.4 BP-Expert

BP-Expert has been developed as part of the COnstruction and Real Estate NETwork (CORENET) programme, which is a key component of the IT2000 Information Technology Masterplan (IT) for Singapore. BP-Expert is an intelligent system, employing AI and CAD, to automate the checking of architectural plans for compliance with the Building Control Regulations. The system will be used to carry out self-checking before submission to the Building Control Division (BCD). It accepts as input building plans prepared with CAD software. It captures knowledge of how to interpret architectural designs as well as how to verify the design against building control regulations. It automatically recognizes the layout of a floor plan, derives spatial relationships between the various building components and checks the design for compliance with the building code. Non-compliances are highlighted, and the architect can correct any design errors until compliance is achieved. The electronic files can then be submitted to Building Control Division (BCD) for final approval.

Further information can be obtained from the following Web site, which has been used as the source for the above description:
http://www.gov.sg/mnd/pwd/bpx/index.htm

3.2.5 Operation

The use of knowledge-based systems is well established in the process and manufacturing industries. Techniques developed for those industries can be transferred to the monitoring of the structural behaviour of buildings. A monitoring system has been developed by BRE to study the in-service behaviour of two steel trusses in a large hall located in Neasden. In addition to the sensors on the truss, two temperature gauges record the ambient temperature in the zone around the trusses. These data are used for system development and a knowledge based monitoring system currently under development is directly linked to the logger.

3.2.6 Property valuation

The University of Portsmouth developed a system for valuing properties using property details from surveys and records of actual auction prices. This system used a neural network and demonstrated that non-experts could give effective valuations. This was very necessary as the introduction of the UK Council Tax required millions of properties to be assigned into bands (DTI, 1998).

3.2.7 Predicting defects in housing construction

The majority of building defects are avoidable and relate to design and construction problems, in addition to poor quality maintenance work and general negligence and abuse by the users. It has been estimated that the annual cost of such problems is around £1000 million in the UK and represents about 95% of all defects. The current techniques employed to predict defects in housing do not offer a facility to construction professionals and workmen for the intelligent application of information at both design and construction stages.

A prototype KBS system was developed at the Sheffield Hallam University. The system incorporates all knowledge related to design specification and codes of practice, materials and components workmanship considerations and procedures. The knowledge collated allows the KBS to be used before or during the construction process. The system may be used during the sketch design and detailed design stage of the construction process (Ahmed and Stephenson, 1997).

3.2.8 Subsidence – diagnosis and management

SCAMS is a KBS developed at the University of Teeside to provide guidance to engineers in the engineering management of subsidence cases (Scott and Anumba, 1996; Scott, 1997). It offers intelligent advice and addresses three key aspects - diagnosis of a subsidence case, choice of an appropriate course of investigations, and specification of effective remedial measures. The knowledge encapsulated within the system has been obtained from literature, domain experts, case studies and an industry survey. The system:

- serves as a decision support system for experienced engineers and provides guidance for inexperienced engineers;
- leads to reduced repair costs due to more appropriate investigations and more effective remedial measures;
- aids understanding and ensures greater consistency in evaluation and management;
- ensures all relevant geotechnical and structural engineering considerations are taken into account;

SCAMS has been evaluated by domain experts and is being developed into a commercial product.

4 How to decide on suitability of a knowledge-based solution for a problem

Many attempts to develop knowledge-based systems have failed. The reasons for failure are normally the same as those for conventional information systems. Failure is not normally due to technical aspects of the knowledge-based technologies used. The most common reasons for failure are: insufficient business justification; lack of support from project stakeholders; and organisational issues.

AIAI at The University of Edinburgh has developed a methodology for determining the feasibility of a given knowledge based system application (Filby 1997). This comprises an assessment of:

1. **Business Feasibility (e.g. improvements in the quality of decision making; a reduction in staff costs; preserving knowledge which was vulnerable to loss; etc.)** weighted against the possible costs that will be incurred e.g. hardware and software costs; running cost (backups and maintenance); etc.
2. Project Feasibility e.g. the commitment, availability and skills of all the project stakeholders should be considered.
3. Organisational Feasibility e.g. whether the organisation is currently undergoing any organisational changes; what impact the system will have on tasks preceding and following the task supported by the system; a full understanding of the main functions/processes along with their associated information; training staff within the organisation to install, maintain and manage information and the proposed technology; existence of a champion to lead the introduction of such systems.
4. Technical Feasibility e.g. the type of task - synthesis tasks are often harder than analysis tasks; risks - tasks with major risks should be identified and their impact on the development determined; these should be implemented first to reduce the overall risk to the project; the type of reasoning –if it is primarily symbolic reasoning based on expertise then a KBS should be suitable; requirement for common-sense knowledge - if this is required to solve the problems, it is likely to be infeasible; etc.

5 Conclusions

- KB/AI techniques can successfully be used to capture and re-use best practice 'knowledge'. This has been demonstrated most clearly in non-construction industry sectors. Consideration should be given to refocusing construction research on to practical industry needs.
- The precise techniques used are of less importance than the industry needs – decision support systems capturing experience can be constructed in many cases using more traditional IT techniques. A methodology to allow the assessment of

an organisation's existing skills and knowledge and to identify the key gaps and opportunities for improvement is needed.

- The small market size for software in the construction industry and other factors make the development of many stand-alone DSS problematic. A more promising approach would be to develop a library of Web-based tools that could be shared. The incorporation of common sense 'intelligence' into Classes of Objects through the IAI is one way forward. The development of tools, which could be used by individual companies or interest groups to add additional, specific and possibly proprietary knowledge, would also be very helpful.
- There is a need for documented Case Studies that demonstrate concrete benefits.
- Means need to be established to allow industry to obtain advice on feasibility of decision support systems to address their needs. This could be a role for a network of experts

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233 USING IMAGES PATTERN RECOGNITION AND NEURAL NETWORKS FOR COATING QUALITY ASSESSMENT

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Abstract

Most current techniques used in construction and infrastructure assessment and quality inspection rely merely on subjective criteria. Such inaccurate or subjective assessment techniques have been identified as a critical obstacle to effective infrastructure or constructed facilities management. This paper illustrates a more objective and reliable assessment method to improve the conditions of the infrastructures or the quality of constructed facilities. The proposed system will automate the coating assessment process by using computers to analyze digital images of the areas to be assessed.

Keywords: Quality Assessment, image processing, pattern recognition, neural networks

1 Introduction

Bridge engineers and owners need accurate, consistent, and reliable information regarding paint system performance for the effective management and rehabilitation of bridges. Such information includes quantitative paint system ratings and accurate estimates of the useful life of the coating system. The extent of coating failure is most important in determining when a coating is to be repaired. Currently, the means available in the evaluation of coating performance is limited. Visual rating of the coating condition, which represents the most established technique, is plagued by a number of significant problems. It does not have the capability to provide accurate, quantitative, and consistent inspection data, thus precluding timely planning of bridge

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management and rehabilitation (Hsie and Chang 1995).

As well as being a safety hazard to the operator and traffic, the current visual inspection procedure is tedious, time-consuming, and subjective. All of the other available inspection methods are strictly localized, contact-point methods which are ineffective for assessment of global coating deterioration. Consequently, the infrastructure community has been looking for a more cost-effective, non-destructive instrument and methodology which would automate the repetitive visual inspection, improve the quality and reliability of inspection, and provide quantitative feedback regarding the paint condition (Chang and Carino 1998).

Therefore, to search for a better method for assessing bridge painting quality, a research project is exploring using computer visual image processing for painting quality assessment. Hopefully, this research can enhance the quality of assessment of steel bridge painting. The purpose of this paper is to present the framework for visual image processing research and its preliminary results.

2 Background

2.1 Prior research in computerized coatings assessment

There have been some similar research efforts performed at the Infrastructure Technology Institute (ITI) at Northwestern University (Shubinsky 1994). The main thrust of that research was the non-destructive evaluation of bridge coatings using several techniques, namely: Color Visible Imaging, Electrochemical Impedance Spectroscopy (EIS), and Infrared Imaging. Based on interviews conducted at ITI by the second author, the research result presented a generic framework, but was not developed to the implementation stage.

An experiment using visual imaging technique was devised for one bridge in order to obtain the amount of damaged areas due to rusting. Additional tests were performed on coated test panels inside the lab (could I have the reference please). One of the research conclusions and recommendations was to develop an applicable system, which should be portable and user-friendly. Moreover, one of the recommendations was to incorporate intelligence in the assessment system (Shubinsky 1994). The undergoing research by the authors is aiming to further explore the development of an applicable and intelligent system for bridge painting quality assessment.

2.2 Pattern recognition

Intelligent systems will be a dominant technology in the near future. Pattern Recognition (PR) techniques are often an important element of intelligent systems, and are used for both data processing and decision making. Broadly speaking, pattern recognition is the science that concerns the description or classification (recognition) of measurements. There is little doubt that PR is an important, useful, and rapidly developing technology with cross-disciplinary interest and participation. PR is not comprised of one approach, but rather is a broad body of often loosely-related knowledge and techniques (Schalkoff 1992).

Pattern recognition techniques assign a physical object or an event to one of several pre-specified categories or classes. Thus, a pattern recognition system can be viewed as an automatic decision rule; it transforms measurements on a pattern into class assignments. The patterns themselves can range from agricultural fields in a remotely sensed image from a satellite to a speech waveform or utterance from an individual. The associated recognition or classification problem could be to label an agricultural field as wheat or non-wheat or identify the spoken word. There are many algorithms for statistical pattern recognition. One of the most widely used algorithms is the K-Means algorithm (Ripely 1996).

2.2.1 The K-Means algorithm

The K-Means Algorithm self-organizes data to create clusters. This algorithm fits the coating inspection application well because of the number of clusters need to be predetermined, which is the case in the inspection process, are: defects and non-defects.

The algorithm uses a sample of feature vectors $V = \{x^{(1)},\ldots,x^{(Y)}\}$ from a population P, but requires the number K of clusters to be given, $K < Y$. The process begins by assigning the first K sample feature vectors $x^{(1)},\ldots,x^{(k)}$ to be centers $z^{(1)},\ldots,z^{(K)}$, respectively, for the K clusters. The algorithm then assigns each of the remaining Y-K sample feature vectors $x^{(K+1)},\ldots,x^{(Y)}$ to the cluster whose center is closest. Then, the sample feature vectors for each K^{th} cluster, in turn, are averaged to determine a new cluster center $z^{(K)}$ for each K^{th} cluster. Next, each of the Y sample feature vectors is again assigned to the class to whose new representative center it is closest.

This process of generating new centers by averaging each cluster and then reassigning all vectors by minimum distance to the new centers is repeated until no clusters change further, in which case the algorithm is finished (Ripely 1996).

2.3 Artificial neural networks

A popular artificial neural network model is the back propagation network model. The basic back propagation model is a three-layered forward architecture. The first layer is the Input Layer, the second layer the Hidden Layer, and the third layer the Output Layer. Each layer contains a group of nodes that are linked together with nodes from other layers by connections among the nodes. Layers are connected only to the adjacent layers. The network is a feed-forward network, which means a unit's output can only originate from a lower level, and a unit's output can only be passed to a higher level. Figure 1 illustrates the basic structure of a feed forward neural network (Zurada 1992).

The Input Layer receives the features of the data that are entered into the neural network. If n feature values are to be entered into the Input Layer, then there must be n nodes; where n is the number of features supplied to the net. A single feature value is inputted into a single input node. The values are passed to the Hidden Layer through connections from the Input Layer. The nodes in the first layer distribute the individual inputs to all of the nodes in the Hidden Layer. The hidden layer acts as the connection between the input layer and the output layer. The main function of the hidden layer is to process the input data during the network training to connect to the output, i.e. to do the regression process (Zurada 1992).

The connections between the layers are weighted to emphasize or de-emphasize the relative value of the input. The Input Layer does not operate on the feature data, but merely passes it to the Hidden Layer. Each node sums the *n* weighted inputs to the Hidden Layer. The value of the summation can be different for each node, due to differently weighted connections between the first and second layers. The values that are summed in the hidden nodes are then passed to the nodes in the Output Layer via another set of weighted connections. Each hidden node is connected with each output node. Although the Hidden Layer may actually consist of several Hidden Layers, some models' Hidden Layer uses only one layer.

The Output Layer generates the output of the neural network. In the same way the Hidden Layer functions, the Output Layer's input values are summed, and the summation becomes the output value. Each output node corresponds to a desired output class. Each node sums the *n* weighted inputs in the Hidden Layer and the values from each output node are compared to each other.

These weighted inputs are summed and used as the node output value. Several Output Layers can exist for a back propagation network. Because the back-propagation algorithm is an iterative algorithm, it can be trained by adjusting the connection weights among the nodes. The weights are recalculated after every complete cycle until the weights converge and the mean square error falls within the specified acceptable range.

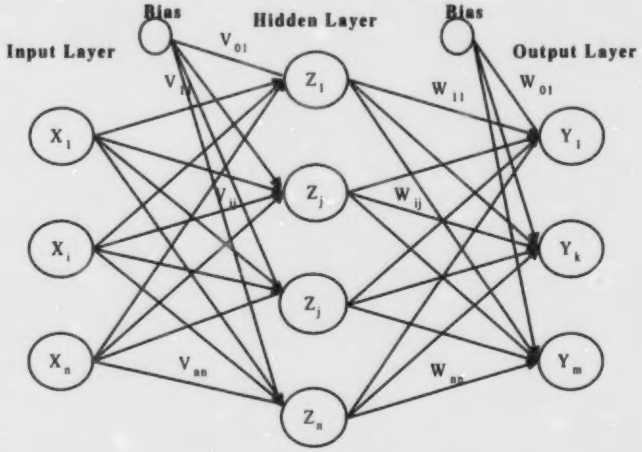


Fig. 1: Neural network for the back-propagation algorithm

3 Proposed assessment system

The basic concept of the decision support system is to obtain digital images of objects to be inspected and identify defects using image analysis techniques. Moreover, sample images will be used to train the system to acquire expert knowledge in identifying the defects and using this knowledge to later assess other coatings. Figure 2 illustrates the working system model. It consists of four main stages.

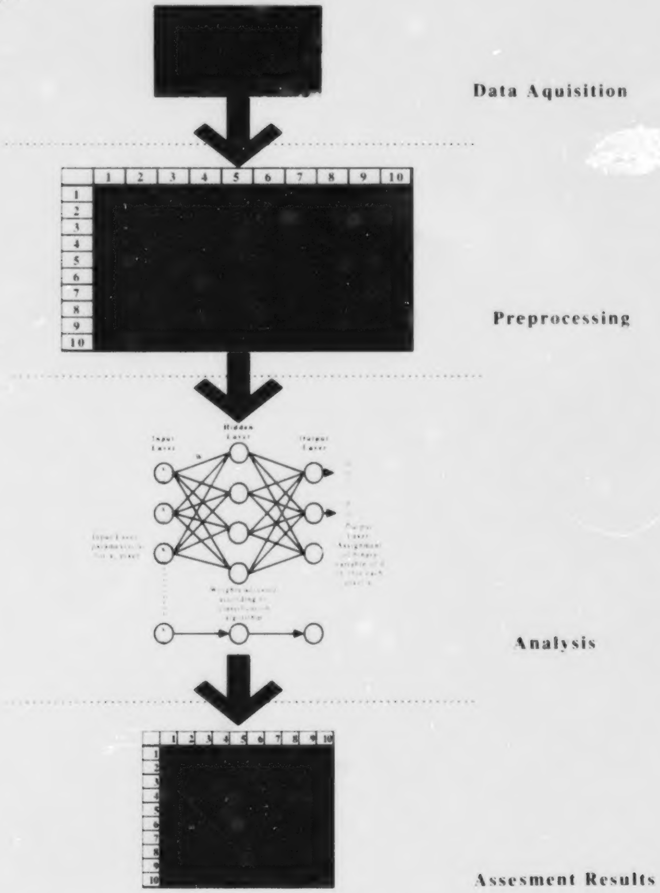


Fig. 2: Hybrid system model

The first stage is Data Acquisition: where digital images for the steel bridge coating (objects) are obtained using a digital camera. After acquisition the images are transferred to the computer on site or in a remote office via any communication protocol.

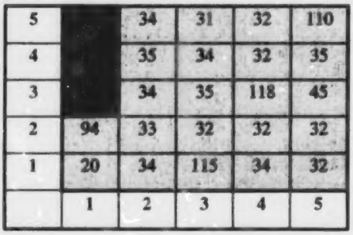
The next stage is the Preprocessing stage, where image analysis techniques are used to analyze and enhance the image by applying algorithms such as filtering and edge detection. Moreover, image pre-processing is used to obtain the numerical parameters of the image such as the gray level and brightness in a numerical format. At this stage a statistical pattern recognition algorithm is utilized to identify defects according to the numerical representation of images.

The next stage is the Processing stage. After being trained, neural networks are used to identify defects in the images by assigning binary variable of 0 or 1 for each pixel in the image. During the network training, the neural network is fed with different images and their parameters such as the pixels' gray levels. The network is also fed mapped values of 0 or 1 for each pixel value. The network will learn to assign the binary variable 0 or 1 for different scenarios according to image parameters.

The final stage is the Assessment Results stage, where quantitative measures of defects are obtained from the output of the previous stage. From mapped output of the neural network, the whole image is represented as 0's or 1's. The 1 values represent the defect; hence, defects can be identified and quantitatively measured. The system can be trained to identify different types of defects according to the specific application.

4 Example

The following example illustrates how a simple (5 pixel x 5 pixel) image could be used to illustrate the methodology of the hybrid system. Consider the image in Figure 3 to be an image of a part of steel bridge beam with a coating on. The darker areas represent defect object (rust) and the lighter areas represent background.



5	■	34	31	32	110
4	■	35	34	32	35
3	■	34	35	118	45
2	94	33	32	32	32
1	20	34	115	34	32
	1	2	3	4	5

Fig. 3: The image gray levels

Step 1 Data Acquisition

A digital image of a steel bridge coating area is obtained and transferred to the computer.

Step 2 Preprocessing

Image analysis software is used to enhance the image and to represent the image in numerical format. Figure 3 shows the sample image with the gray level shown for each pixel.

The next step is to apply the statistical pattern recognition algorithm to classify the numerical values into two clusters: rust or no rust. The result of this classification is then passed to the third step. K-Means algorithm is used for classification because it best fits this specific application in that the number of clusters to classify must be predetermined.

Given the data set obtained from the image numerical presentation in Figure 3, the K-means Algorithm is applied.

$V = \{232, 34, 31, 32, 110, 231, 35, 34, 32, 35, 135, 34, 35, 118, 45, 94, 33, 32, 32, 32, 20, 34, 115, 34, 32\}$

Using the K-Means Algorithm, the data set is classified into two classes: rust and non-rust pixels. After that, all pixels will be assigned a binary variable of 1 or 0, depending on whether it is a rust or non-rust pixel.

Select randomly, the first two samples as initial centers.

$z^1 = 232 \quad z^2=34$

Next assign each sample to the class with the closest center, i.e. to class 1 if it is closer to $z^1 = 232$ and to class 2 if it is closer to $z^2=34$.

The following table shows the difference between each pixel value and the initial two centers and hence to which class it is assigned. Note that the difference is calculated based on the gray level, not based on the location of the pixel. The gray level is considered a third dimension for each pixel.

Table 1: First iteration for K-Means algorithm

Pixel Value	Difference from z1	Difference from z2	Class 1	Class 2
232	0	198	x	
231	1	197	x	
135	97	101	x	
94	138	60		x
20	212	14		x
34	198	0		x
35	197	1		x
34	198	0		x
33	199	1		x
34	198	0		x
31	201	3		x
34	198	0		x
35	197	1		x
32	200	2		x
115	117	81		x
32	200	2		x
32	200	2		x
118	114	84		x
32	200	2		x
34	198	0		x
110	122	76		x
35	197	1		x
45	187	11		x
32	200	2		x
32	200	2		x

$C_1 = \{232, 231, 135\}$

$C_2 = \{34, 31, 32, 110, 35, 34, 32, 35, 34, 35, 118, 45, 94, 33, 32, 32, 32, 20, 34, 115, 34, 32\}$

Figure 4 shows the initial clustering.

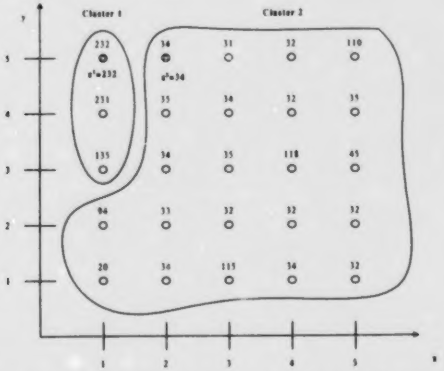


Fig. 4: Initial Clusters (With initial centers; z^1=232 and z^2 =34)

Next, each cluster's samples are averaged to obtain new optimal centers.

$$\text{New center } z^1 = \sum \frac{\text{Gray levels values in cluster 1}}{\text{number of points in cluster 1}} = 199.3$$

$$\text{New center } z^2 = \sum \frac{\text{Gray levels values in cluster 2}}{\text{number of points in cluster 2}} = 50.78$$

The same procedure is applied again to find the distance between each sample and the two centers and assign the sample to the cluster with the closest center.

Table 2: Second iteration for K-Means algorithm

Pixel Value	Difference from z1	Difference from z2	Class1	Class 2
232	32.7	181.22	x	
231	31.7	180.22	x	
135	64.3	84.22	x	
94	105.3	43.22		x
20	179.3	30.78		x
34	165.3	16.78		x
35	164.3	15.78		x
34	165.3	16.78		x
33	166.3	17.78		x
34	165.3	16.78		x
31	168.3	19.78		x
34	165.3	16.78		x
35	164.3	15.78		x
32	167.3	18.78		x
115	84.3	64.22		x
32	167.3	18.78		x
32	167.3	18.78		x
118	81.3	67.22		x
32	167.3	18.78		x
34	165.3	16.78		x
110	89.3	59.22		x
35	164.3	15.78		x
45	154.3	5.78		x
32	167.3	18.78		x
32	167.3	18.78		x

$C_1 = \{232, 231, 135\}$

$C_2 = \{34, 31, 32, 110, 35, 34, 32, 35, 34, 35, 118, 45, 94, 33, 32, 32, 32, 20, 34, 115, 34, 32\}$

The class assignment did not change and hence the algorithm is finished. The final clusters are shown in Figure 5.

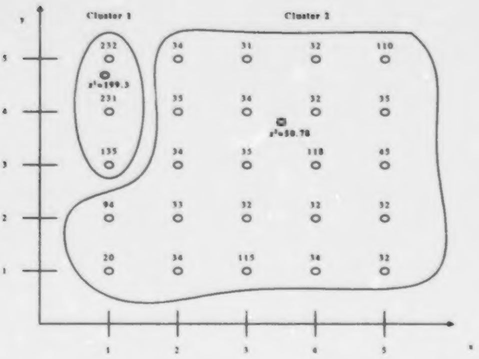
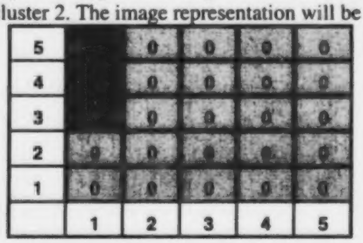


Fig. 5:Final Clusters

Finally, each sample is assigned a binary variable of 1 if it belongs to cluster 1 and 0 if it belongs to cluster 2. The image representation will be as shown in Figure 6.



5		0	0	0	0
4		0	0	0	0
3		0	0	0	0
2	0	0	0	0	0
1	0	0	0	0	0
	1	2	3	4	5

Fig. 6: Rust Identification in the Image

Step 3 Analysis

Data from the image shown in Figures 3 and 6 will be used to train the neural network. The purpose of using the neural network is to accommodate for errors that may occur when depending only on statistical pattern recognition. Adjustments are made using experts' knowledge and then the neural network is trained in order to automate the process in the future.

The complete neural network will consist of three layers: the input layer, the hidden layer, and the output layer. The input layer consists of the image data and has four elements: The x-axis location of the pixel, then the y-axis location of the pixel, the value of the gray level of the pixel, and finally the difference between the gray level of the pixel and a predetermined threshold value. The predetermined threshold value will be determined by experts' knowledge of coating inspection in coordination with results from image analysis. Another method for determining the threshold value is to apply image processing segmentation techniques. In this example, the predetermined threshold is 120. Table 3 shows the data entry for the neural network.

Table 3: Neural network data input

Input #	Location (x)	Location (y)	Parameter 1 (Grey Level)	Parameter 2 (Difference from Pattern Threshold: 120)	Output (Binary Variable)
1	1	1	20	100	0
2	1	2	94	26	0
3	1	3	135	-15	1
4	1	4	231	-111	1
5	1	5	232	-112	1
6	2	1	34	86	0
7	2	2	33	87	0
8	2	3	34	86	0
9	2	4	35	85	0
10	2	5	34	86	0
11	3	1	115	5	0
12	3	2	32	88	0
13	3	3	35	85	0
14	3	4	34	86	0
15	3	5	31	89	0
16	4	1	34	86	0
17	4	2	32	88	0
18	4	3	118	2	0
19	4	4	32	88	0
20	4	5	32	88	0
21	5	1	32	88	0
22	5	2	32	88	0
23	5	3	45	75	0
24	5	4	31	89	0
25	5	5	110	10	0

Weights and biases are used by the network to emphasize or de-emphasize the importance of some data points. The initial values for weights and biases are chosen randomly but there are some guidelines for that choice. It is important to avoid choices of initial weights and biases that would make it likely that either activation or derivative of activation is zero. Also the value of weights and biases should not be too large, or the initial input signals to each hidden or output unit will be likely to fall in the saturation region, in which error can not be reduced.

5 Summary

A decision support system for steel bridge coatings assessment has been presented. The objective is to introduce the visual image processing on coating quality assessment. The image processing system uses the advanced technologies in the fields of machine learning, pattern recognition, and image analysis for steel bridges coating assessment. The basic concept of the research is to automate the assessment process by taking digital images of the rust areas and analyzing the images to identify and measure coating defects. The system will make the assessment process more objective, quantitative, and reliable.

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234 OPERATIONS DOCUMENTS: ADDRESSING THE INFORMATION NEEDS OF FACILITY MANAGERS

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Abstract

We have reviewed intranet technologies as a strategy for improving the availability and quality of building information to support operations. Discussions with facility managers and design consultants have revealed problems with the as-built documents that are typically provided by the AEC team. Experiments with intranet technologies have led us to a concept of just-in-time operations documents that can be implemented using Web technology. The paper examines formats, structure and content for these operations documents. It describes an early prototype implementation that tested the feasibility of our concepts.

Keywords: as-built drawings, facility management, facility operations, information technology in facility management, maintenance management.

1 A mismatch of formats, structure and content

In the life cycle of a building, authorities suggest that the overwhelming majority of expenses occur during the operations stage. Arguably, facilities are the largest asset of many businesses (Rondeau, Brown and Lapides 1995). Maintenance, remodeling, replacement of components and daily facility operations consume a large portion of the cost of doing business. In comparison to the needs of design and construction, little attention has been paid to information needs of facility operators. Perhaps as a consequence, the topic of "as-built" information strikes a chord of concern among many facility managers. The "as-built" drawings or "record" drawings that are commonly delivered by designers are not an adequate information base for operating a building. The AEC industry needs new approaches to delivering and

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structuring facility information for use by owners and operators.

These perceptions are supported by several research explorations. In a survey of master planners, facility managers and maintenance personnel at Army installations, researchers found that the as-built documents were often incomplete, inaccurate and poorly structured for supporting operations (Liu et al. 1994). In other discussions with facility managers, the issue of as-built drawings emerged as a problem area of widespread and intense concern (Johnson and Clayton 1998). The use of new information technologies to address these problems has led to our formulation of "operation documents" to specifically address the needs of the operations phase of a building (Clayton et al. 1998). While as-built drawings or record drawings are intended to document the constructed state or designed state of a facility, operations documents are intended to be dynamic, living records of the evolving state of a facility to support operations, maintenance and renovation.

The dissatisfaction with as-built drawings arises from multiple flaws. At a simple level, *formats* may be inappropriate. The medium for the representation may be wrong. The information may be delivered only as paper documents. Even digital documents may require a conversion effort to adapt the information to the operators' software systems. Beyond format problems, there may also be a mismatch in information *structure*. Structure is a meta-level characterization of general content that helps to define the semantics of the information. For example, layers in CAD drawings provide structure to the graphic information. However, layering conventions that support a design-oriented view of the information may not support the needs of owners and operators. Finally, there may be a mismatch in *content*. Information needed for operations may simply be missing. Almost as bad, there may be an overwhelming quantity of irrelevant information.

This paper describes a research effort to define better 1) the information needs of facility operators, 2) the delivery step by which that information may be collected from designers and other consultants, and 3) the opportunities afforded by new information technologies. The research was undertaken as a partnership with the Facility Operations Department of USAA, a Fortune 500 financial services enterprise. Although we have focused strongly upon the needs of USAA, we believe our conclusions are generalizable to other owners of large facilities. Within USAA, we focused upon mechanical, electrical, plumbing and control systems.

Our methods were the following. To define the issues and identify problems, we conducted discussions with USAA personnel and various design and construction consultants. We also familiarized ourselves with intranet technologies by review of literature and practical application. These studies helped us to conceive and clarify a vision of information systems to support operations. Rapid prototyping of that vision enabled us to prove the concept and demonstrate its feasibility.

2 Operations documents issues

Discussions revealed several themes that characterize building documentation to support operations. These are:

1. *Collections of diverse information.* The information used by operations personnel is complex and has diverse origins. Some of the kinds of information are architectural and engineering drawings, equipment schedules, riser diagrams, test and balance reports, equipment monitoring data, maintenance manuals, maintenance schedules, emergency procedures, and design rationale.
2. *Diverse delivery formats.* A wide variety of consultants, contractors and suppliers produce information without being aware of the information needs of operators. Information is delivered piecemeal in formats and structures that may be difficult to incorporate into an integrated information system.
3. *Integrated views across functional systems.* Rarely does the structure of facility documents support easy retrieval of information across discipline or system boundaries. While designers and constructors divide responsibilities to focus upon single systems, the building operators must perceive that all systems contribute to an interrelated whole.
4. *Feedback for document maintenance.* As-built drawings often become out of date with startling rapidity. Assuring automatic and reliable up-date procedures as operators change the facility is crucial to long-term success of an information system for facility operations.
5. *Support for training.* A particular problem area has been documents for training. Conceptual overviews, usage scenarios, and emergency procedures must be presented to new or transferred employees.
6. *Inclusion of design rationale.* Missing from current facility documents are clear and complete records of design rationale. Many questions arise during operations regarding the intentions of the designers. Design rationale is also an important component of training.
7. *Approachable technology.* The user interfaces of an operations document information system must be familiar and easy to learn. Operations personnel are not information specialists and should not be expected to master sophisticated but arcane commands, queries and paradigms.

3 Intranet technologies

We focused our search for solutions upon emerging information technologies that enable the creation of intranets. An intranet is a secure network that is internal to an organization and uses Web technology to distribute information and services. We have explored several basic technologies that can contribute to an intranet-based facility operations document system. These include:

- *Web browsers and HTML:* These are established and popular technologies for publishing across a network. Information resides on a server computer and is delivered to a client using the Hypertext Markup Language (HTML) format and the Hypertext Transfer Protocol (HTTP). The server need not be the same hardware or software platform as the client. A Web browser provides a user interface by which people can request information from the server.

- *Relational Database Management System:* RDBMS systems, such as Microsoft SQL Server and Oracle, are a fundamental repository for information that is structured into fields and records. Open Database Connectivity (ODBC) is a widely supported standard for performing queries on many brands of RDBMSs.
- *Active Server Pages (ASP):* ASP is Microsoft's tool for including programming logic into the delivery of information on the Web. With ASP, one can insert HTML fragments, perform database queries, and process the values in user input fields to generate HTML code on-the-fly. Thorough manuals on the use of ASP are available through the commercial press (Johnson 1997).
- *Drawing Web Format:* DWF is a file format established by Autodesk for vector drawing information on the Web. Drawings in DWF can be zoomed and panned while maintaining visual integrity and dimensional accuracy. DWF files can have embedded links, multiple named views, and layers that can be toggled on and off. The settings can be controlled via JavaScript and parameters in a URL.
- *XML:* Extended Markup Language (XML) provides enriched structure to Web documents that enables machine processing to support multiple uses. XML is closely related to Standard Generalized Markup Language (SGML), a proven technology for defining the structure for classes of documents. With XML one can define new, custom tags in a Document Type Definition to enable machine parsing and manipulation.
- *On-line redlining:* A number of tools are available that allow simplified editing of a CAD file to support mark-ups, note errors, and indicate changes. The edited information is kept in a separate file from the original CAD drawing to establish authorship of the suggested changes.

4 Just-in-time operations documents

The use of hypertext for operations manuals has been established in the process plant industry (Tidwell and Leckington 1994). Emerging intranet technologies in the context of operations documents has led us to formulate a concept of "just-in-time operations documents" that extends and refines earlier work. Our vision is that information technologies can actively and automatically retrieve and collect relevant information from data repositories in response to task-oriented requests by operations personnel. Rather than relying upon ill-structured archives of information or at best upon a comprehensive operations manual, operations personnel can be provided with concise, complete documents that are focused upon a task at hand. Emerging Web technologies provide the means for implementing this vision on a corporate intranet.

Our concept relies upon facility information being recorded and stored in electronic formats and structures. Three technologies in particular appear highly relevant. Conventional drafted representations of the facility must be created using Web-enabled CAD systems with hyperlinks embedded into the drawings. Client-server relational databases provide repositories for tabular data. Text that does not lend itself to a tabular presentation can be tagged using XML to relate it to the information in databases and in Web-enabled drawings.

Key to the concept is the programmatic generation of operations documents that are specific to particular tasks. We refer to this as "task-centric." A person involved in operating the facility can request an operations document by filling out forms in Web documents. The forms collect specifics of task and location. A Web server can then match the parameters against rules to choose a template for the task-centric documents. A script can then retrieve bits of information from various sources and bring them together into a custom document. This document is then delivered in HTML format back to the requestor.

Task-centric documents may be explained using an example. One task that operations personnel may face is the repair or replacement of a faulty fan-coil unit. Upon discovering that a unit is performing poorly, a technician must inspect a variety of documents to troubleshoot the problem:

- the drawings of the mechanical system,
- the manufacturer specifications,
- the test and balance reports for the distribution tree,
- diagrams of the electrical circuits that feed the unit,
- diagrams of the chilled water delivery pipes,
- the performance record produced by monitoring and controls systems,
- the maintenance records and
- the design intent for the unit.

At present, this information must be collected from a variety of drawings, memos, binders and documents, most of which exist only on paper and buried within irrelevant other information. A task-centric document would filter out the irrelevant information and collect these and many other pieces of information into a single project manual. The technician could then refer to the task-centric document for most or all of the information for the project. The concept of just-in-time operations documents adds to this task-centric approach automation that collects the many pieces of information on demand by the user.

5 Implementation

Emerging intranet technologies provide a technical foundation for implementing an effective information system for operations. We have conducted tests in the form of rapid prototypes of software to establish architecture and design principles for such an information system. Some of the major components of the system as we envision it are 1) generic repositories of facility information; 2) a link farm; 3) XML documents recording design rationale; 4) server procedures that generate Web pages; and 5) electronic redlining. Although the creation of a prototype is still underway, these concepts appear to us to be likely or inevitable parts of an information system that is a solution to the needs of facility operations.

5.1 Generic repositories

The problems of coordinating the delivery of facility information suggest that a successful information system will impose minimal restrictions upon outside information providers such as design consultants and construction contractors. Rather than mandating delivery of information in sophisticated standard formats and structures, we suggest that outside providers can employ tools that are widely accepted and deliver facility information in simple and straightforward formats and structures. The adaptation of the information for use in internal information systems can be deferred to the owner/operator organization. As long as information is delivered in digital format, it can be massaged to conform to the needs of internal information systems.

We suggest that an owner organization should emphasize delivery of information in "natural" formats. For example, drawing information should be delivered in a vector format such as Autodesk's DWG or DWF. Schedules, such as door schedules, window schedules, and pump schedules, are tabular information. They should be delivered not as images drawn in the CAD system but as spreadsheet or database tables. Test and balance reports are also tabular by nature and should be delivered as spreadsheets or database tables. Design rationale or operations procedures should be delivered as word-processed documents. These formats and structures place minimal or no demands upon consultants. In some cases, use of the appropriate format may even lead to savings to the consultants.

The degree of structure that should be provided by consultants is an open question and also a moving target. At one extreme is the idea of very little structure to information when it is delivered. Structure must be applied either as a "data scrubbing" step by the internal personnel or must be created on the fly by scripts. This pole requires little expense on the part of the external organizations but a high degree of expertise on the part of internal personnel. At the other extreme are strict requirements for format, structure and content to which consultants must conform. Outside consultants may demand increases to fees to offset perceived effort and risk. The second approach also requires a large degree of up front effort to formulate the standards. As consultants become more savvy with Web technology there should be an opportunity to out-source more of the responsibility for structuring information.

At this time we suggest that a facilities organization can collect facility information from consultants in appropriate formats but with a relatively low level of structure. After receiving information in these natural formats, personnel in the owner/operator organization can place it into repositories by type, such as a directory of drawing files, or a database of pump data, or a directory of design intent descriptions. By using scripts, macros and automatic conversion utilities, the owner organization can convert the data into the specific formats and structure required by the information system. Scripts can carry out further manipulation and refinement of facility information at time of use under the concept of generating task-centric documents.

5.2 Link farm

Key to making use of the generic repository of information is the application of powerful data management tools to the hyperlinks themselves. The term "link farm" refers to a collection of hyperlinks that can then be incorporated into one or more documents (Light 1997). A level of indirection in links adds utility to the links. The apparent link, embedded in an HTML document, actually points to the link farm. The link farm retrieves the actual link and delivers the requested document. By implementing the link farm using a relational database, sophisticated operations upon selection sets of links may be used to increase the utility of the link mechanism. One-to-many links, many-to-one links and context-sensitive links can be easily implemented to provide users with an enriched access to information. The database can also be used to manage links, such as redirecting links to accommodate changes in file locations, and global substitution of links to up date information.

Not only does the link farm play a role in managing links, it can also provide strategic information for the continued growth and refinement of the information system. The link farm can log link traversals and collect data from the users regarding usefulness of information. Developers and maintainers of the system can use the automatic feedback to anticipate information needs and prioritize conversion of existing documents into the information system.

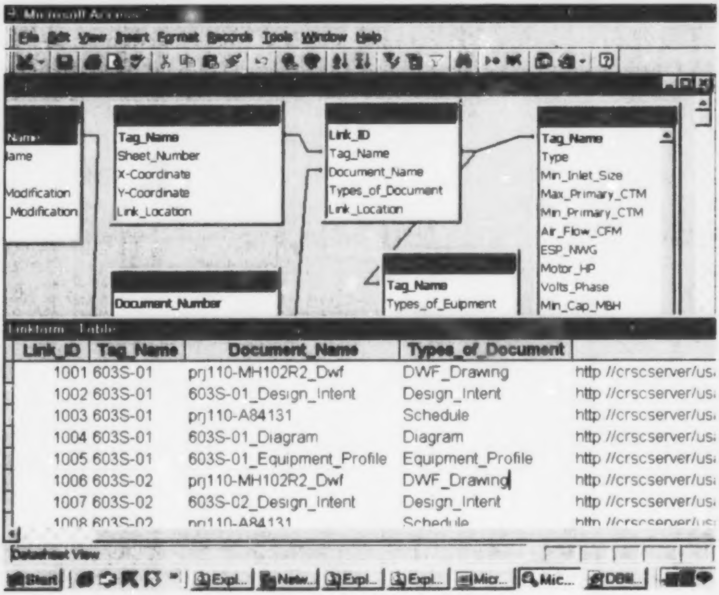
A link farm for operations documents is illustrated in Figure 1. It has been implemented using a Microsoft Access relational database. Each link is represented by a record in the table. Many links that are embedded in drawings or text files can be represented by the same record, providing many-to-one linking. Also a single link in a drawing may lead to more than one record in the table, providing one-to-many linking. Links may be retrieved by queries upon any field or combination of fields. Side effects of queries also create records in another table to log the use of links.

5.3 XML for design rationale

Documentation of design rationale for use in training manuals, troubleshooting and redesign is important enough to warrant special consideration. XML could be an appropriate technology for addressing design rationale. Using XML would require developing a document type definition (DTD) that can be used to express design rationale. A DTD defines the semantics and syntax of tags that can be embedded in a text document to indicate structure and meta-content.

Convincing designers to employ a standard format for recording design rationale is likely to be difficult or impossible. One solution could be to employ an expert to undertake "harvesting" of design rationale from a design team. Equipped with custom XML editors and inventories of facility components, the design rationale expert can interview members of the design team and record their responses in an XML document instance, embedding appropriate tags. The tags can then be used by the information system to extract particular pieces of information for composition into just-in-time operations documents.

Additional research is necessary to establish useful standard structure and content for design rationale. We are exploring the use of concepts of form, function and behavior as guiding principles for documenting design rationale. Form (sometimes termed "structure"), function and behavior have been established as a useful formalism for representing design reasoning (Kuipers 1984, Gero 1995). Text could be tagged both by component and as form, function or behavior. Scripts could then retrieve from the XML document the appropriate information to compose "just-in-time" training manuals or task-centric explanations of design intent.



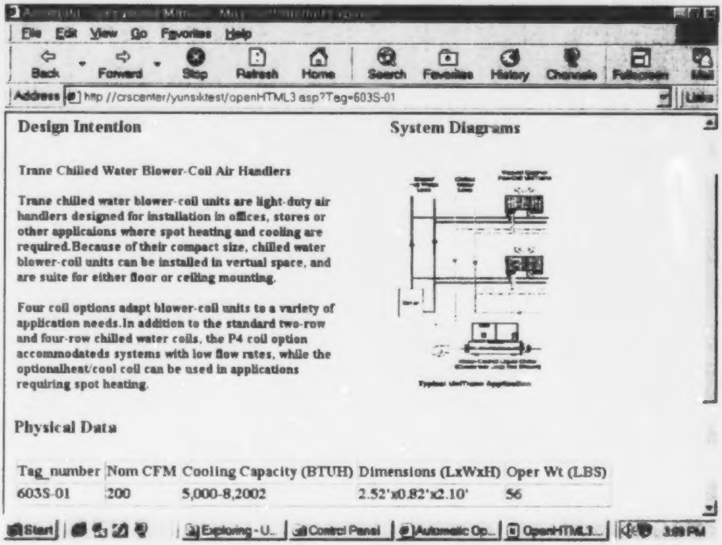
Link_ID	Tag_Name	Document_Name	Types_of_Document	
1001	603S-01	prj110-MH102R2_Dwf	DWF_Drawing	http //crscserver/us
1002	603S-01	603S-01_Design_Intent	Design_Intent	http //crscserver/us
1003	603S-01	prj110-A84131	Schedule	http //crscserver/us
1004	603S-01	603S-01_Diagram	Diagram	http //crscserver/us
1005	603S-01	603S-01_Equipment_Profile	Equipment_Profile	http //crscserver/us
1006	603S-02	prj110-MH102R2_Dwf	DWF_Drawing	http //crscserver/us
1007	603S-02	603S-02_Design_Intent	Design_Intent	http //crscserver/us
1008	603S-02	prj110-A84131	Schedule	http //crscserver/us

Fig. 1: Link farm for just-in-time operations documents

5.4 Generated intranet pages

Our experiments have employed Microsoft's Active Server Pages to generate HTML documents on the fly. Links to records in the link farm are embedded into drawings and text documents. JavaScript and VBscript are used to define templates that receive arguments declaring the project and the context for the requested information. Upon traversing a link, the scripts take over to produce customized HTML documents that are delivered back to the requestor. The script can retrieve data from a database, drawing files, and images and blend them with fragments of HTML code. An example of a just-in-time operations document is shown in Figure 2.

The operations documents created with this system are tailored to the particular needs of the operations personnel. Of course they can be printed, but they may also exist only as digital documents for the moments that they are referenced. The operations documents are transitory and are delivered just in time to support a particular task.



http //crscenter/yunsiktest/openHTML3 asp?Tag=603S-01

Design Intention

System Diagrams

Trane Chilled Water Blower-Coil Air Handlers

Trane chilled water blower-coil units are light-duty air handlers designed for installation in offices, stores or other applicaions where spot heating and cooling are required.Because of their compact size, chilled water blower-coil units can be installed in vertual space, and are suite for either floor or ceiling mounting.

Four coil options adapt blower-coil units to a variety of application needs.In addition to the standard two-row and four-row chilled water coils, the P4 coil option accommodateds systems with low flow rates, while the optionalheat/cool coil can be used in applications requiring spot heating.

Physical Data

Tag_number	Nom CFM	Cooling Capacity (BTUH)	Dimensions (LxWxH)	Oper Wt (LBS)
603S-01	200	5,000-8,2002	2.52'x0.82'x2.10'	56

Fig. 2: Example of just-in-time operations document showing the design intent, system diagram, and scheduled information.

5.5 Electronic redlining

Feedback to the information system is crucial to keep the portrait of the facility up to date. Forms to collect feedback for a project can be automated with ASP. Upon a query for facility information for a particular task, a work flow management capability of the information system could monitor progress. The system could produce a form to collect comments regarding the adequacy of the documents that were generated for the project. The software guides the user through updating the documents to reflect new conditions.

Our prototype incorporates CADViewer by ArNoNa Internet Software Inc., an electronic redlining tool written in Java that works with the DWF format (ArNoNa 1998). Mark-ups can be made to a DWF file and then saved as a separate file. The mark-up files, updated databases, and messages to the document maintenance staff serve as feedback by which documents are kept up to date.

6 Further explorations

Our working prototype has led us to confidence in the vision portrayed above. An appropriate next step is to implement further to sharpen our perception of technical challenges and obstacles. Empirical testing of a trial system can provide subjective evaluations by actual operations personnel. Comparative trials can determine the extent of benefits of such a system in improved performance by building operators. By keeping track of the time that is spent building the just-in-time operations documents system, we can gain quantified indicators of the expense of such a system when it is scaled up. The link monitoring features of the link farm can guide further development.

Once sufficient experiments are executed in the laboratory, the implementation can be moved to the field. Initially, the implementation could address just one unit of the facility, such as a section of a building or a small building. Detailed records of personnel time expended in constructing and maintaining the information system will provide data for cost/benefit analysis of a full implementation. After a time period, field surveys can compare the actual facility against the operations documents to see whether the feedback has been effective. A field survey of a facility unit that has been managed with conventional paper documents can establish a benchmark.

By conducting discussions with industry personnel and examining current documents, we have obtained an understanding of information that is needed to support operations. A thorough survey of intranet technologies has then led us to envision "just-in-time operations documents." Quick experimental prototypes with example facility documents have allowed us to prove the technical feasibility of the concept. The prototypes have led to the clarification of an extensive research program that is likely to lead to quantifiable and significant benefits. The findings can then be directed toward the broader industry and have an impact upon standards that lead to widespread increases in productivity.

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235 A INTEGRATED DECISION-SUPPORT SYSTEM MODEL FOR CONSTRUCTION MANAGEMENT EXECUTIVES

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Abstract

In recent years, with the increasing popularity of the World Wide Web, integrated data management tools have enabled organizations to automate their management information systems. The application of information technology (IT) in the construction industry mainly involves planning, monitoring, reporting and similar managerial functions that, in unison, support effective decision-making. Istanbul Technical University's Project Management Center (ITU-PMC), was established as a research institution under the ITU Rectorate, with the main aim of planning, executing and controlling all construction projects within the university campus. One of the initial activities undertaken by the ITU-PMC, in enabling an efficient and effective management system was a research project concerning *Management Information Systems for ITU Construction Projects*. The objective of this project was to develop an integrated data management tool including decision-support utilities for communicating, organizing and managing project information using web-based technology and the network. This paper describes the model that was developed to enable the effective management of ITU's campus construction projects. The model entails an automated system for the effective management of multiple construction projects, enabling efficient budget utilization by offering an elaborate decision-support system for executive managers.

Keywords: information technology (IT), management information systems (MIS), Internet, computer integrated construction (CIC), decision-support systems, web-based project management, Istanbul Technical University-Project Management Center (ITU-PMC).

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1 Introduction

Compared with many other industries, the construction industry faces high levels of complexity, uncertainty, discontinuity, as well as many restrictions. The construction process involves a large number of participants, various forms of project organization, and the use of numerous different types of computer applications. These characteristics bring forth the need for intensive data exchange and information sharing based on the integration of various applications. This can be achieved through a more efficient utilization of information technology tools for the management of construction information processes. IT comprises many techniques, methodologies and paradigms, which have considerable potential for improving the management of information within the construction industry. The vast topic of IT includes general artificial intelligence systems, knowledge-based systems, intelligent decision-support systems, and the ever-popular Internet, which are fields that are continually growing independently, but proportionately with each other. The ever-growing attention given to information resources suggests that better management of these resources become critical to project success. Dutton et al. (1996) present their views on future research concerning the Internet and knowledge-based systems for the construction industry. They emphasize the need for fast, efficient, peer-to-peer communications facilitating easy supply of information and knowledge when virtual teams through remote working require it.

Björk (1994) points out that, in establishing the infrastructure for data structuring and transfer standards for CIC applications, digitized construction information services and changing patterns of organizing projects become critical issues. Currently, construction companies are occupied with a variety of research and development efforts toward the improvement of transformation processes. Executives address the need for intelligent integration of information in supporting decision-making for effective management in all stages of design and construction.

Emerging object-oriented tools and environments offer new possibilities for the development of models for integrated management construction information systems. The approaches discussed and the model presented in this paper aim to show how communication and decision-making in the construction industry can be improved by means of intelligent knowledge-based systems.

2 The role of distribution technology in construction information systems

Advances in information technology have created a wide range of research developments in construction. Some examples of the content of research conducted in this area is as follows:

Björk (1992 and 1993) proposes a model consisting of a conceptual model of spaces, space boundaries and enclosing structures and discusses the problems in the development of this model. Björk (1993) also presents suggestions for the integration of construction information at the document-level. Augenbroe (1993) discusses the design systems in a computer integrated manufacturing context for the construction of information models. Björk et al. (1995) present the development of product models in information modeling, while Eastman (1993) discusses the computer integration of design and knowledge in construction.

Turk (1997) suggests that information technology has assisted the collaboration and coordination of many professionals. The nature of the construction industry is such that virtual teams are often brought together for projects before being broken apart again upon completion. The software applications used may also vary from one construction project to another. The organizations and individuals forming the team contribute to the project with their specific skills and resources, which may include legacy applications and data. The collaboration effort created by the team environment must therefore be carefully coordinated and managed. Brown et al. (1996) points out that any integrated environment should provide a means by which the component objects contributed by organizations and application vendors can inter-operate in a seamless way.

IT researches proactively support the construction industry by offering an infrastructure for better-constructed facilities in less time and at lower costs. Researchers of this subject have suggested various methods for information integration in construction. These methods can be categorized as: communication between applications (achieved through specific software integrating a unique and invariant set of chosen applications); integration through geometry (often the case in commercial CAD packages where integration is based on and limited to geometrical information); knowledge-based interfaces (linking multiple applications and multiple databases); and integration through central project databases (holding all the information relating to a project according to a common conceptual model). Bohms et al. (1994) propose a model (namely, ATLAS) towards a computer-integrated system for large scale engineering projects. Dubois et al. (1995) developed a model (COMBINE) involving conceptual modeling approaches for HVAC and building design. Bjork (1994) presents the RATAS project, which sets an example for cooperation between industry and research towards computer integrated construction. Aouad et al. (1995) proposes the ICON model for effective building design and construction management. Effective management of construction projects depends on easy access to and control of data, especially data pertaining to cost and schedule control functions. Long recognizing the need to integrate these interrelated functions, researchers have proposed conceptual models towards this purpose. However, a functional design of an automated solution that would support the need for integrated cost and schedule control, as well as providing distributed access to data for different processing needs is generally lacking. In their data storage model, Abudayyeh and Rasdorf (1991) suggest how such an automated solution can be effectively designed and developed.

3 Web technology in project/construction management

The World Wide Web not only provides a means for information display and gathering and efficient accessibility to applications, but also grows to become a platform for design collaboration by increasing the flow of information between and within all computerized organizations. However, there is still a need for an environment in which planners can contextually visualize various types of planning information to better support their decision-making processes. Advances in network computing are rapidly changing the way management functions are being performed. With the maturation of technologies, especially Internet-based technologies, concepts that have been proposed for Web-Based project management and software development are now realized. In recent years, a great deal of research has been carried out into the creation of integrated data management tools that enable organizations to automate systems towards product development by using web-based technology. Dikbas and Yitmen (1998) developed a model of approach showing an example of an integrated management information system in multi-project scheduling using a collaborative web-based project management tool for Eastern Mediterranean University's campus construction projects.

Increased popularity of Internet technologies and applications nowadays offer new opportunities for the construction industry. Portable software modules commonly referred to as *plug-ins*, allow for the viewing and simple manipulation of data through a Web browser without requiring a commercial license of the original software application used in creating the data. These tools can be used to integrate heterogeneous distributed data from several sources on a single user's screen to support decision-making. Similarly, integrated project data management tools create a project environment based on web technology. Examples to some existing Web-based tools that are somewhat related to construction management are **MesaVista**, **WebProject** (Java-based) and **Spider**, which are collaborative project management environments designed for product development teams using Web technology for faster access to up-to-date information in their decision-making processes.

Such tools bring together the information produced by disjointed tools in an intelligent manner, on a common platform, accessible through a common interface--the web browser. Project management scheduling data can be viewed in a Java-enabled web browser and fit into overall engineering and managerial processes and organization workflow.

4 Overview of the case and problem definition

Istanbul Technical University started a donation program within the framework of the "Year-2001 Projects" which was conceptualized in 1997. The realization of numerous construction projects has been enabled as a result of the funds made available through this donation program. These projects, with a total closed area of approximately 30,000 m^2 and estimated valued of $50 Million, include dormitories, a student dining-hall, a student cultural center, a closed swimming pool, a child-care center, an elementary school, and miscellaneous renovation projects.

With such a rapid spurge of projects, a need was recognized for a system that would ensure the effective management of the donation funds in the construction of ITU's campus projects. With the main aim of enabling such management and decision-making tools, ITU-PMC initiated a research project that forms the basis of the model presented in this paper.

As a starting point, the availability of software packages relevant to construction/project management in the local market, and the suitability of these packages for integrated use was investigated. It was found that both locally produced and foreign software packages are available and concurrently used in our country. Locally produced software packages offer the benefits of taking local conditions into consideration. Available foreign software packages can be collected under two categories; (1) those that are adapted to accommodate specific conditions in Turkey, (2) those that are generic for standard usage in any country, and not specific to Turkey.

Even though a large variety of project management software packages are currently being used in our country, when considered in an integrated environment, none of these packages are capable of complete and effective integration. They either become outdated during the duration required for adaptation, thereby losing the capability of dealing with recent changes; or the interfaces used within the applications are not capable of supporting fast and detailed transfers of information. Additionally, locally produced software packages are only capable of supporting single aspects of the construction management processes (such as only bill of quantities). The use of multiple applications in the same environment requires the use of multiple interfaces, which in most cases are only capable of transferring basic data between applications.

At the present time, it can be argued that a sufficiently effective system has not yet been developed to provide fast and accurate information transfer to upper-level management. ITU-PMC started to develop such Web-based MIS and decision-support tools with the aim of eliminating some of the deficiencies in the existing systems. The proposed system allows each participating organization to continue using the specific software packages they are accustomed to in planning and managing their projects. By integrating data extracted from these specific software packages (for example, software packages that are used independently for quantity surveying, schedules, budgets, and so forth) the system generates a variety of reports, which become extremely important especially in decision-making at the multiple project level. In the ITU context, the system has enabled the Rector to develop a variety of scenarios, based on project criteria and priorities, in establishing profitable and beneficial budget allocations in the realization of multiple campus construction projects.

5 Objectives of the study

The aim of the system described in the proposed model is to provide easy access to current information for upper-level management during analysis, decision-making, and control processes. The objectives of this project is to develop a decision-support system with multiple-criteria decision-making facilities for optimum distribution of the budget allocated for construction through donations and state funds, and to prioritize ongoing and upcoming campus projects.

The optimum model for such an integrated system, capable of performing the tasks explained in Part 4, is one that consists of a structure independent of its application components, but yet is capable of supporting each application within its system. In other words, the system must consist of an integrated network of application modules. In generating such a model, the following problems must be considered:

- There are numerous software packages that work under different systems and that do not have common interfaces.
- The above factor brings about the requirement for an enormous number of codes necessary to enable software integration.
- Rapid developments in the software industry continually render the systems outdated over very short time spans.
- Since different firms may be using different applications, the model would need to provide the required flexibility in accessing different combinations of applications.
- Considering that each client organization may have different versions of the same applications, and to ensure compatibility of new versions with previous versions of these applications, the system must have the capacity to support different versions of the software packages.

The model would need to have the following characteristics in order to offer effective solutions to the problems listed above:

- The program application can not be monolithic. The program must be adaptable to different operational systems, hardware, specific customer demands, and other such variables.
- The system must consist of independent components. Each component must have the capability of being easily installed into, or changed within, the system.
- The system must support the simultaneous use of different versions of the same applications.
- The system must be designed in a *chaotic* structure in order to support a variety of operation environments utilized by the component applications.

6 Proposed model and method

In this model, the applications are integrated within the system through independent interfaces. Interfaces are instances of the same class for common applications; therefore, duplication of interface codes can be avoided. Each interface consists of three main functions. As displayed in Figure 1, (1) marks the application's specific component that allows access to the application database; (2) provides the most important function of the interface in that it allows each application to be used independently, as well as jointly, within a common format. For example, in an interface that is used for two different time planning applications, while (1) is specific to each application, (2) produces data that determines how time planning information will be stored in the system. Thereby, it filters the applications used for time planning. Part (3) of the interface saves accessed data on the system's database in order to avoid redundant repetition of the conversion processes during future queries.

In order to offer a more detailed understanding of the interface functions within this system, an example of a common construction management application is observed in the following sections. The area circled with a dotted line in Figure 1 is circled similarly in all illustrations concerning this example case. This example represents any application requiring multi-project information, such as decision support systems, S-Curves, and so forth.

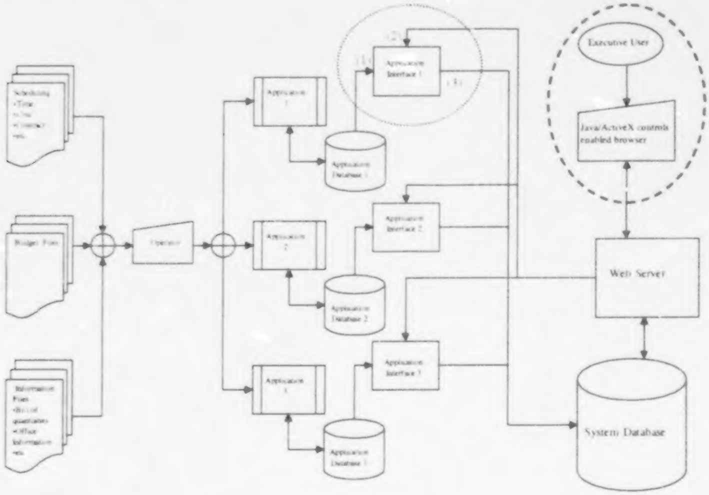


Fig. 1: General structure of the proposed model

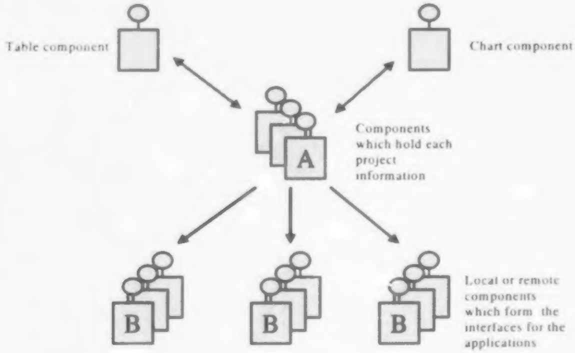


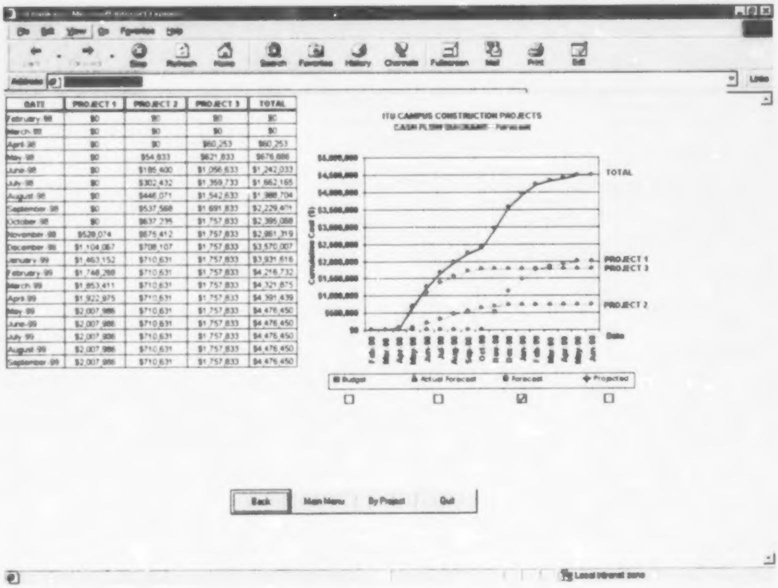
Table component
Chart component
A
Components which hold each project information
B
B
B
Local or remote components which form the interfaces for the applications

Fig. 2: Relationship between interface components

7 Sample implementation

A user interface displaying multiple projects is an environment that consists of components that operate through different processes. The A-type components shown in Figure 2 are defined by the user application that provides the interface with application-specific data. These components can be used in any user interface application. Figure 3 shows a sample user interface. The interface is capable of creating the S-Curve of multiple projects, and tabulating combined budget information. The application responsible for the creation of tables and charts attains all required information from respective A-Type components. Figure 2 displays the programming model within an application.

Each A-Type component is dynamically created and used to store the data of one specific project. Similarly, when its related project is not accessed, an A-Type component can be excluded from the process. A-Type components must have the capability of reading databases of different applications in collecting project data. In achieving this function, A-Type components utilize B-Type components, which are responsible for converting data from various applications within the system into a pre-defined format. B-Type components are written specific to applications, and may support more than one application. However, the data format created for A-Type component utilization is standard.



DATE	PROJECT 1	PROJECT 2	PROJECT 3	TOTAL
February 98	$0	$0	$0	$0
March 98	$0	$0	$0	$0
April 98	$0	$0	$60,253	$60,253
May 98	$0	$54,833	$621,833	$676,666
June 98	$0	$185,400	$1,056,633	$1,242,033
July 98	$0	$302,432	$1,359,733	$1,662,165
August 98	$0	$446,071	$1,542,633	$1,988,704
September 98	$0	$537,568	$1,691,833	$2,229,401
October 98	$0	$637,235	$1,757,833	$2,395,068
November 98	$528,074	$675,412	$1,757,833	$2,961,319
December 98	$1,104,067	$708,107	$1,757,833	$3,570,007
January 99	$1,463,152	$710,631	$1,757,833	$3,931,616
February 99	$1,748,268	$710,631	$1,757,833	$4,216,732
March 99	$1,853,411	$710,631	$1,757,833	$4,321,875
April 99	$1,922,975	$710,631	$1,757,833	$4,391,439
May 99	$2,007,986	$710,631	$1,757,833	$4,476,450
June 99	$2,007,986	$710,631	$1,757,833	$4,476,450
July 99	$2,007,986	$710,631	$1,757,833	$4,476,450
August 99	$2,007,986	$710,631	$1,757,833	$4,476,450
September 99	$2,007,986	$710,631	$1,757,833	$4,476,450

Fig. 3: A sample user interface

In multiple project environments, such as the one shown in Figure 4, each project is displayed through a different A-Type component. Each A-Type component is responsible for providing all information concerning the project it is linked with. For example, when the user wants to access budget information concerning a specific project, the related A-Type component communicates with the B-Type component it is linked to in obtaining the desired information from the relevant application's database. The application (or version of the application) containing budget data may vary from one project to another. The system may therefore contain different versions of B-Type components to accommodate such differences. A-Type components are functionally capable of utilizing as many different B-Type components as necessary in gathering the required data.

In order to provide fast access to previously converted data, B-Type components save status information on the system's database. If the status information shows that the converted data is still current, this data can be rapidly accessed through the system's database without going through the conversion process. B-Type components perform a status control on the data requested by the A-Type component. Based on this information, A-Type components either attain the required data from the system database, or wait for the B-Type components to perform the necessary conversions in forwarding the required data.

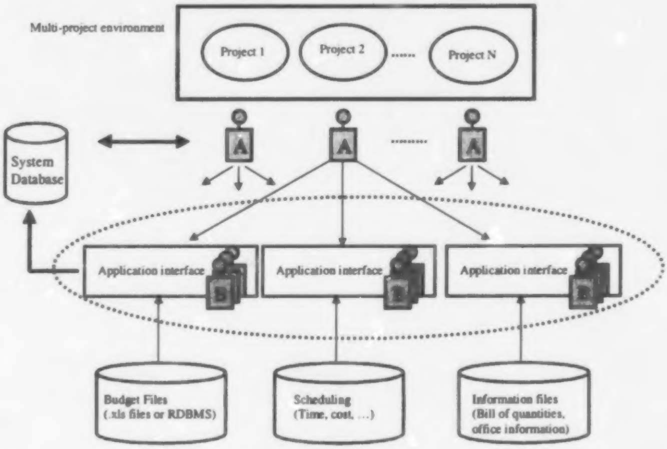

Multi-project environment
Project 1
Project 2
......
Project N
A
A
....
A
System Database
Application interface
B
Application interface
B
Application interface
B
Budget Files (.xls files or RDBMS)
Scheduling (Time, cost, ...)
Information files (Bill of quantities, office information)

Fig. 4: The operation system of the model's application interfaces

A component-based approach is used in the application of this model. The aim here is to create a non-monolithic system with functions capable of supporting the addition and removal of components without requiring alterations to the general structure of the system itself. Therefore, a flexible system consisting of many components and interfaces required for internal communication within the system has been created in this model, as shown in Figure 5. Each component is designed to perform a specific function independent of the others. Apart from the components that make up the system's mainframe and the ones that define the required links between the components, the system has a very dynamic structure.

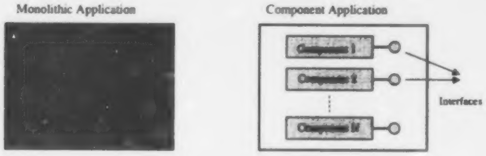


Fig. 5: Component-based application model

All of these interfaces are implemented as remote objects and placed in a component pool, as shown in Figure 6. There are two methods that can be used in this type of implementation. The first method is based on Microsoft's COM and DCOM approach. Objects can be implemented as ActiveX controls in order to be used in ASP scripts. The second method is to remain in the Java environment and to implement these objects as server objects. Even though these two approaches are similar in principle, a problem arises while implementing both methods simultaneously. Method 2 (Java-based technologies) is being used in this project. However, based on requirements brought forth by other platforms, either method can be used in future applications.

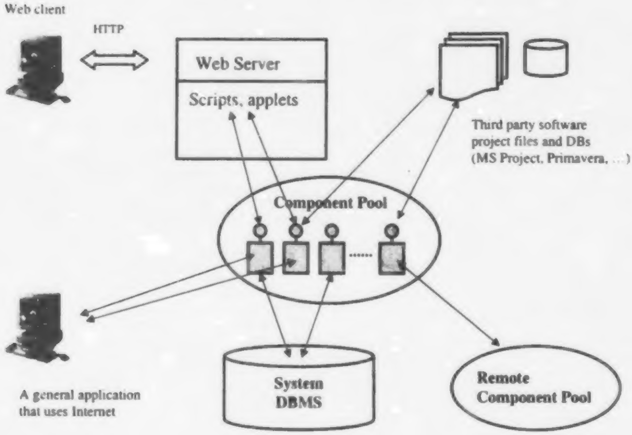


Fig. 6: General view of the entire system

Two types of clients can use component pools. (1) Web clients, (for example, Microsoft ASP scripts can create and use COM objects). (2) Java Applets can use remote objects by RMI (Remote Method Invocation). Another method of using these objects is by accessing them through general applications, which use Internet as the communication platform. All applications written in any language (Java, C++, Visual Basic, etc.) can access and use these objects. The appropriate client type is selected based on the type of the application needed. Internet technologies are rapidly merging. It is anticipated that in the near future, the main access to such objects will be through the web. However, the second type of client may offer more effective usage until certain performance problems have been overcome in the system. Regardless of the selected client, the data is processed in the same way because the components of the system remain the same.

The S-Curve and tabulation example mentioned previously confirms the project aims at the secondary level. The Java Applets/ActiveX controls create the necessary reporting environment.

The decision-support system at the third level is realized by the shaping of project data based on user input via A-Type components. The user is able to perform a variety of analyses based on different project priorities. These analyses can be saved and compared with previous analyses. The system thereby provides a flexible environment with a reporting system and a decision-support module enabling the user to access a variety of interfaces without changing the existing infrastructure of the system. One of the most beneficial aspects offered by the third level of this system is that it allows for executive managers to create and analyze a variety of scenarios concerning the execution and prioritization of projects based on self-entered subjective criteria and budget information.

8 Conclusion

The model presented in this paper proposes a solution to one of the most frequently discussed questions in today's construction management context—*how best to manage multiple projects*. Previously developed models (as discussed in parts 1-3 of this paper) accommodate general project management requirements. Although construction management and project management techniques have a great deal of overlap, the application of such a model for the construction sector poses several additional issues.

The main problem in developing integrated automated information systems for construction management purposes is that the large number of different software packages used in the construction sector render the integration process quite complicated. Generally very elaborate and specific applications are used for construction planning and management tasks such as quantity take-off/cost estimation, time scheduling/management, and cost/budget control. Additionally, the software packages used for these tasks are very likely to vary from one construction firm to another.

In general, the report formats used by executive managers and decision-makers are very similar, in that they contain the same type of information. The difficulty lies in formulating a process for collecting data from various software packages, accumulating this data in a multi-project environment, and formatting this data to create integrated reports. When this process is considered in the Web-environment, interface requirements create further complications.

The system discussed in this paper has been tested and is currently being successfully used in the management of ITU construction projects. Reports are effectively and rapidly being conveyed to management (in this case, the Rector) and tracked through the ITU network and the Internet. The system has enabled a more efficient use of the university's budgetary resources as well as faster and more effective decision-making in general.

Being Web-based, this automation system provides easy and rapid access to project information from anywhere, at any time, ensuring timely decision-making. The project team[i] is now working on software applications that will assist managers of construction firms in viewing the gain/loss ratios of their firms, and in decision-making during the bid-phase of construction projects.

8.1 Glossary of terms

Application Interface(s):	Application-specific program that integrates its application to the system with a standard interface.
System database:	Relational Database Management System (RDBMS) that organizes all the data infrastructure of the system. It includes all the system data and holds all the data and status information provided by application interfaces.

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Webproject, http://www.wproj.com

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System Analysis: Fatma Isik, Baris Erolcay, Esra Atalay
Model Development: Attila Dikbas, Bulent Morten, Ibrahim Yitmen, Sevda Bayramoglu

236 CO-ORDINATION OF CLASSIFICATION FOR PRODUCT MODELLING AND ESTABLISHED BUILDING CLASSIFICATIONS

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Abstract

Computer based information management introduces new possibilities and puts partly new requirements on information and classification systems. The rapid develop-ment and dissemination of information technology within the construction sector demands international co-ordination of standards and classification systems. This paper presents the preliminary results of a study of the product model classification systems IFC and POSC/Caesar in relation to the established building classification systems as defined in ISO 12006-2 and the Swedish BSAB 96. The study is part of a project with the aim to analyse the structure, scope and direction of development for these different systems, and to investigate the possibilities of co-ordination and co-operation between them. It shows a need for co-ordination of concepts in the ontological and the domain levels.

Keywords: CAD, design, databases, building classification, interoperability.

1 Introduction

1.1 Co-ordination of systems for information sharing

The rapid development and dissemination of information technology within the construction sector demands international co-ordination of standards and classification systems. Computer based information management introduces new possibilities and puts partly new requirements on classification systems. This paper reports some preliminary results of an ongoing investigation of the prerequisites for co-ordinating classification systems for product modelling in the construction context, with established building classification systems. The study is financed by the Swedish national research program "IT Bygg&Fastighet 2002"

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(IT Construction & Facility Management 2002), concerned with information technology for Construction and Facility Management.

Established building classification systems studied here are the ISO standard 12006-2 "Organization of information about construction works – Part 2: Framework for classification of information" (ISO 1997), and the Swedish building classification system BSAB 96 (BSAB 96 1998). Classifications for product modelling studied here are the POSC/Caesar Data Model and Reference Library (POSC/Caesar 1998), developed by the POSC/Caesar Association, and the Industry Foundation Classes, IFC, developed by the International Alliance for Interoperability, IAI (IAI 1997b). The project analyses the structure, scope and direction of development for these different classification systems and investigates the possibilities for co-ordination.

2 Established building classification

2.1 ISO 12006-2

The recently developed international standard ISO/CD 12006-2 "defines a framework and a set of recommended table titles supported by definitions, but not the detailed content of these tables". It is intended to be used as a framework for developing specific building classification systems by organisations on a national or regional basis (ISO 1997).

ISO/CD 12006-2 identifies the main classes that are of interest to the construction sector's building classification for purposes of CAD, specification, product information and cost information systems (ibid:iv). The scope of the standard is the complete life cycle of construction works within building and civil engineering. It lists recommended tables according to particular views or principles of specialisation and gives examples of entries that may occur in these tables (ibid:1).

The identification of classes in ISO/CD 12006-2 is based on views on construction works. The functional and spatial views are based mainly on relations to the user or the environment, see figure 1, sec. 2.2. Other views are related to a process model and identify construction resources, construction processes and construction results. The classes *construction entity* and *construction complex*, are based on a functional view in relation to use. The class *space* is based on a combined spatial and functional view on a construction entity. Physical parts of construction entities are classified in three separate classes based on different views. These classes are: *element*, e.g. floor, based on a functional view, *work result*, e.g. structural precast concrete, based on a construction result view, and *designed element*, e.g. floor of structural precast concrete, based on a combination of functional and construction result views.

Each view consists of classes that together enable a complete classification of the things in the collection; i.e. every thing is classified, and belongs to only one class in each level of abstraction of the view. This enables quantity take-off to be carried out independently in the *element*, *designed element*, and *work result* views, for example with the purpose of cost estimates.

Established classification systems do not handle geometrical properties of construction works, they are supposed to be used together with drawings that contain this information. A physical part of a building is determined by the combination of drawing information and the classifications as *element* and *work result*.

A main feature of building classification systems that adhere to ISO 12006-2 is that they support design by independently allowing functional and compositional views on physical parts of buildings (Ekholm and Fridqvist 1998).

2.2 BSAB 96 and its theoretical foundation

The BSAB system has a long-standing tradition as the Swedish de facto standard for product specification, materials specification, cost estimates and document management (BSAB 96 1998). The conceptual scope of the BSAB system is similar to that of the ISO Framework standard. However, the use scope of the BSAB system is the Swedish construction industry. The classes are developed together with the users of the system, and represent established industry practice. The classes and their names are well known and used in documents of all sorts throughout the construction and facility management processes.

The classification tables of BSAB 96 adheres to the ISO 12006-2 Framework standard. The tables in BSAB 96 contain subclasses of the main classes in the Framework. Both standards are based on common principles for building classification established already with the SfB-system from 1950 (ibid). Just like the ISO Framework standard, the BSAB 96 system is based on the idea that the main classes express different views on construction works. In BSAB 96 this idea is grounded in a theoretical model based on generic property theory and systems theory (ibid). According to this model, a system is composed of interrelated parts, that may be systems themselves, and has relations to an environment. A functional view, "top-down", on a system concerns its interaction with the environment, and a compositional view, "bottom-up", concerns its composition and intrinsic relations. The main classes in ISO 12006-2 and BSAB 96 are developed from these views. The principles for applying these theories to building classification are presented in (Ekholm 1996).

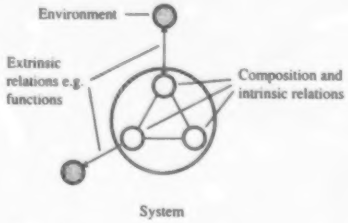
Environment
Extrinsic relations e.g. functions
Composition and intrinsic relations
System

Fig. 1: Basic properties of systems

3 Levels in databases for product design and documentation

3.1 Level structure

Research within product modelling has led to a basic understanding of how to structure databases for the purpose of product documentation. Björk has identified five levels of abstraction in building product modelling: the information modelling language, the generic product description model, the building kernel model, the aspect model and the application model (Björk 1995). The first three levels correspond to those identified in this analysis, the information modelling language level, also called the data definition language level, the ontological level, and the domain level. The domain level may be specified in subsequent levels of relevance, e.g. those proposed by Björk.

An *information modelling language*, or *data definition language*, supports the definition of database objects, e.g. entities and relationships (Date 1990:36). The EXPRESS language is an example of a data definition language developed to enable product modelling. EXPRESS is part of the ISO STEP standards (ISO 1994). The EPISTLE, POSC/Caesar, and IFC information systems all use EXPRESS.

The concepts in the *generic product description level* or *ontological level* represent the most generic properties of objects in the domain of discourse. The concepts in this level may be related in an ontological model. One example of an ontological model is the theoretical foundation of BSAB 96 presented above (BSAB 96 1998). The ontological model makes up a theoretical foundation for defining and relating the most generic aspect views on the objects in the domain. The result is a generic classification framework. In order to support design, the framework must differentiate among and allow combinations of spatial, functional and compositional views (Ekholm and Fridqvist 1998).

The classes in the *domain level* constitute a framework for classification of the domain specific objects. Every domain framework is based on presuppositions in the ontological level, explicit or implicit. The domain classes are subclasses in different degrees of specialisation of the main aspect classes defined in the ontological level. The domain framework may also contain domain specific relations and attributes. The domain framework may be organised and stored as a library of predefined classes from, for example, classification systems and earlier projects. During design this information can be combined to make up project specific descriptions of domain objects.

4 POSC/Caesar

4.1 Introduction

POSC/Caesar is a joint initiative of the Petrotechnical Open Software Corporation and the CAESAR Offshore Project. The objective of the POSC/Caesar project is to develop a standardised product model for handling life-cycle information about oil and gas facilities (POSC/Caesar 1998). The product model is developed on the basis of the EPISTLE framework (Angus and Dziulka 1998). The work has resulted in practical means for handling product information based on a data model and additional library classes.

The POSC/Caesar project is of specific interest to the construction sector since it represents an attempt to create a computer based platform for integrated information management. It concerns the oil- and gas industries, but considering plants and other civil engineering works, these have much in common with building construction. For example, many of the library classes concern construction works.

4.2 The POSC/Caesar meta model

The data definition language for the POSC/Caesar approach is based on a subset of the concepts of the EXPRESS information modelling language. This subset of EXPRESS is called the POSC/Caesar Meta model; it is the most abstract POSC/Caesar model.

4.3 The POSC/Caesar data model

4.3.1 Background

The following presentation of the POSC/Caesar Data model concerns the version called "Snapshot E" (POSC/Caesar 1998). The scope of the POSC/Caesar Data model is classes considered of importance for handling life-cycle information in a generic way about oil and gas facilities (ibid). The POSC/Caesar Data model is based on the principles of the EPISTLE Framework, but Snapshot E, marks a radical change in fundamental conceptual structure compared with the EPISTLE Framework (ibid).

4.3.2 The class/instance dichotomy

The most fundamental entity in the POSC/Caesar Data model is the *thing*. A *thing* represents something material or abstract. It has two subclasses, *object* and *association*. Association entities relate object entities. Subclasses of *association* are both abstract, representing conceptual associations like *classification* and *characteristic_possession*, and concrete, representing factual relations such as *connection*, *composition*, and *transportation*.

In POSC/Caesar, an *object* has an "independent existence". The *object* is distinguished from an *association*, which relates *object* classes. The *object* class has two subclasses, *instance_object* and *class_object*. The *class_object* refers to "a collection of well determined things". The *instance_object* is defined as "A type of thing that is individual in nature"; it is not a "class, group, or set of things". A reason for the distinction between *instance_object* and *class_object* is the concern to differentiate between representations of one identified member of a class, and representations that regard every member of the class. *Person_class*, a subclass of *class_object*, can be used to exemplify how POSC/Caesar implements this. Examples of *person_class* are "rich people" and "Australian people", a rich person and an Australian would be members of these classes respectively. The entity specific_person is defined as an "instance object that is a particular human being or group of human beings". A person_classification is a subtype of the classification association. The person_classification entity associates a specific_person with person_class, the former as member of the latter.

4.3.3 The classes *functional_object* and *physical_object*

Of specific relevance to discuss in this context are *functional_object_class* and *physical_object_class*, both subclasses of *object_class*. A *functional_object* represents a functional view on an object in the domain. The definition of *functional_object* is: "A type of instance of object (*instance_object*, author's remark) that is a function or role and may be involved in many activities, considered independently of the physical objects that may undertake the roles from time to time. Roles may be active (making it happen) or passive (happening to). *Functional_object* must be either Facility, Flow or Service" (POSC/Caesar 1998).

A *physical_object* is "A type of instance object that obeys the laws of physics. This includes material, energy and space. A physical object is either a specific or a typical physical object." The *physical_object* is not defined by other characteristics than that its is a concrete thing; seen as a view, it identifies objects by concrete existence.

In principle the same object may be found both as a *functional_object* and as a *physical_object*. The reason for this is that function may be used as a basis for classification of physical_object. One example of this is the subclass of *physical_object* "gas detector", with the definition: "device supposed to detect certain types of gas molecules" clearly describing functional characteristics. However there are other characteristics than function that determine membership of *physical_object*, for example, an object may be defined as a product of a member of a method activity class. This resembles the construction result view in established building classification.

4.4 The reference data library

The objective of the Data Model is to provide the basic class structure of the Reference Data Library, RDL. Each of the main classes in the RDL may be further specialised according to domain specific needs. The RDL is intended to be used both as a design and documentation framework. In the latter case the RDL is intended have a separate project database consisting of subclasses and instances referring to a factual facility e.g. an offshore platform. This is implemented at present with the Åsgård B floating gas platform (Port 1998).

4.5 POSC/Caesar and established building classification

The POSC/Caesar system may in principle be used for construction information. The classes of ISO 12006-2, and BSAB 96 can be part of a specific Reference Data Library developed for the construction industry. In the Reference Data Library, these classes may be accommodated as subclasses of *functional_object_class* and *physical_object_class*. The classes that are based on a functional view can be sub-classes of the *functional_object_class* "facility" in POSC/Caesar. Designed elements and construction products, both grouped by function but based on combinations of views, as well as work result class based on a compositional view could be subclasses of *physical_object* in POSC/Caesar. However, it remains to investigate in greater detail how classes for construction can be accommodated in POSC/Caesar.

5 IFC

5.1 Introduction

The goal of IAI, Industry Alliance for Interoperability, is "enabling interoperability between AEC/FM applications from different software vendors" (IAI 1997a). This goal is to be achieved through development of the Industry Foundation Classes, IFC. The objective of IFC is to "provide a framework for sharing information between different disciplines within the AEC/FM industry".

The Industry Foundation Classes, IFC, are divided into four separate model levels: *Resources Layer*, *Core Layer* with *Kernel and Core Extensions*, *Interoperability Layer*, and *Domain Model Layer*. All the IFC schemas are developed using the EXPRESS data definition language.

5.2 Resources layer

The IFC Resources are classes that may be referenced by classes in every level of the IFC class hierarchy. The Resource classes are *IfcUtilityResource*, *IfcMeasureResource*, *IfcGeometryResource*, *IfcPropertyTypeResource*, and *IfcPropertyResource*. The *IfcUtilityResource* includes IFC-classes for the concepts Identifier, Ownership, History, Registry and Table, to be used in project administration. The *IfcMeasureResource*, is adapted from ISO 10303 part 41 Measure schema, and specifies units and measures that may be assigned to quantities. The *IfcGeometryResource* specifies the resources for geometric and topological representation of the shape of a product. These resources are partly developed as adaptations of ISO 10303 part 42: Integrated Generic Resources. Geometric and Topological Representation (IAI 1997b:4-40). The *IfcPropertyTypeResource* defines the kinds of property definitions that can be attached to objects and relationships. The *IfcPropertyResource* comprises classes for the concepts "actor", "classification", "cost", "material", and "date/time". Among others, one subclass of *material* is a list of all kinds of material. The class *IfcClassification* makes it possible to categorise objects according to specific classification systems.

5.3 Core layer with kernel and core extensions

The Core Layer consists of the IFC Kernel which provides all the basic concepts required for IFC models, it is "a kind of Meta Model that provides the platform for all model extensions" (IAI 1997a:6). These constructs are not AEC/FM specific, as are the extensions to this core (IAI 1997b:7-100). The classes of the Kernel are *IfcObject*, *IfcRelationship* and *IfcModelingAid*. The *IFC Resources* together with the *Core Layer* constitute a generic framework for product modelling in the ontological level. However, the identification of framework classes is not based on an ontological model.

The Core Extension Layer contains extensions for the Kernel classes *IfcProduct*, *IfcProcess*, *IfcDocument*, and *IfcModelingAid*. The core extensions are a specialisation for the AEC/FM domain of classes defined in the Kernel. The *IfcProduct-Extension* defines concepts like element, space, site, building, and building storey (ibid:8-111). The *IfcProcessExtension* has subclasses, which intend to "capture information concerning the work required in order to create a product". It is possible to define work tasks and resources used in these. Subclasses of *IfcDocumentExtension* will allow "specifications for the information content of typical document types encountered within building construction". Presently only cost schedules are covered. *IfcModelingAidExtension* has subclasses to aid in the development of Project models, e.g. *IfcDesignGrid* and *IfcReferencePoint*.

5.4 Interoperability layer

The *IfcSharedBldgElement* in the interoperability layer "covers the definition of building elements that are shared among several IFC domain or application type models" (ibid:12-147). Subclasses here are e.g. *IfcBeam*, *IfcBuiltIn*, *IfcColumn*, *IfcCovering*, *IfcDoor*, *IfcFloor*, *IfcRoofSlab*, *IfcWall*, and *IfcWindow*.

The *IfcSharedBldgServiceElements* in the interoperability layer defines concepts for interoperability in the building services domain (HVAC) (ibid:13-162). Classes in this level are *IfcElectricalAppliance*, *IfcEquipment*, *IfcFixture*, *IfcDistributionElement*, *IfcEngineeringMaintenence*, and *IfcManufacturedElement*.

5.5 Domain model layer

Domain models provide classes that are specific to a particular application within the AEC domain. In version 1.5 there is a sparse selection of subclasses of *IfcArchitecture*, *IfcHVAC*, and *IfcFacilitiesMgmt*.

5.6 IFC and established building classification

The *IfcProductExtension* classes, e.g. *IfcBuildingElement*, *IfcSpace*, and *IfcBuilding*, bear similarities with, and belong to the same level of abstraction as, the main classes defined in the ISO 12006-2 Framework standard. Likewise, the subclasses of *IfcSharedBldgElement* and *IfcSharedBldgServiceElements* in the Interoperability layer seem similar to, and are defined in the same level of abstraction as, the BSAB 96 classes.

As shown, there is a significant overlap between some IFC-classes and established classification systems. There is need for a strategy to resolve this potential conflict. The possibility to make a reference from an IFC-class to an external classification system through the class *IfcClassification* is no solution, since the class definitions may not be consistent, and the class scopes may be different.

In established classification, the class *designed element* serves the purpose of enabling a combined functional and compositional view. The latter seems to be the objective of the *IfcSharedBuildingElement*. Subclasses of *IfcSharedBuildingElement* have names that indicate a functional view, but have in their definitions both material, geometry and functional attributes, e.g. the *IfcBeam* is "a horizontal, or nearly horizontal structural member designed to carry loads" (IAI 1997b:12-149).

There are no subclasses of *IfcBuildingElement* that remind of *work result* classes like *masonry* or *in-situ-concrete* of BSAB 96. Objects defined by such class attributes may also be of interest to handle separately from the role they play in a construction.

Superficially, the IFC system shows significant overlap with ISO 12006-2 and BSAB 96. However, the IFC system is not based on separation of views. The main principle is to attach attributes to the *IfcElement* and its subclasses. One problem seems to be that the *IfcBuildingElement* classes are already having attributes that might not conform to the ISO 12006-2 standard. It remains to study how the classification structure of IFC can be co-ordinated with established industry standards, e.g. with the purpose to support a differentiation of views.

The approach in established building to "categorize elements according to primary functional role or as part of a system" is criticised by IAI for limiting the modelling capacity (ibid:2-15). The approach is an "attempt to avoid this by defining model elements, functional roles, and systems separately so that an element can assume multiple roles and/or be a member of multiple systems" (ibid). In order to support design, there is a possibility to attach attributes to objects and relationships (IAI 1997b:5-74).

The freedom of defining and combining attributes of a model object is in established building classification achieved by separating the spatial, functional and compositional views. For example, any drawing object referring to, and representing spatial, or geometrical, properties of parts of buildings may be assigned to any *element* (functional view) or *work result* (compositional view) or *designed element* (functional and compositional view). However, in practice there are limitations to these combinations. The relations between elements and geometry has been studied in the NICK project (Tarandi 1994), and the relations between element and work result based on industry practice are expressed in the designed elements table in BSAB 96 (BSAB 96 1998).

6 Concluding remarks regarding the need for co-ordination between systems

6.1 Theoretical background, level structure and views

An overview of the structure of the analysed classification standards is presented in Table 1 below. ISO 12006-2 is a generic classification framework for the construction domain. It is not based on an explicit ontological framework, but adheres to the same principles as BSAB 96. The BSAB 96 is an example of a domain specific classification system. It is based on an explicit ontological model, which is used to define the main views and classes.

POSC/Caesar and IFC have a wider scope than established building classification systems. They are developed to completely support computer based information management. For example, they include geometry definitions and specify relations between classes. The need for co-ordination, mentioned in section 1.1, primarily concerns the established classes covered by the established classification systems.

The POSC/Caesar Data Model is a generic framework for design and documentation of artefacts in the ontological level, but it is not based on an explicit ontological model. The Reference Data Library is a domain framework for design and documentation of oil and gas facilities, based on the Data Model. It would be possible to develop a Reference Data Library also for the construction industry, based on the POSC/Caesar Data Model.

Table 1: Level structure of the analysed classification standards

Standards/ Levels	**ISO 12006-2**	**BSAB 96**	**POSC/ Caesar**	**IFC**
Data definition language	(English)	(Swedish)	POSC/Caesar Meta Model	EXPRESS
Ontological level	(Systems model)	Systems model	POSC/Caesar Data Model	Core Layer and IFC Resources
Domain Generic level	ISO 12006-2 Framework	ISO 12006-2 Framework	Reference Data Library	Core Extensions
Domain Specific level		BSAB 96 Classes	Reference Data Library	Interoperability Layer

In IFC, the Core Layer together with the IFC Resources constitutes a generic framework for product modelling in the ontological level. However, it is not based on a generic framework for the AEC/FM domain. The Interoperability Layer is to be developed into a domain specific class library. A limitation of the IFC-system is that its basic class structure is not based on a differentiation of views.

In order to enable integration between these different systems, it is necessary that they have a shared ontological view, classification approach and level structure. An international standardisation of ontology and classification principles for the AEC/FM domain would enable this integration. Concerning the generic classes for the AEC/FM domain, co-ordination is required between ISO 12006-2, a future construction specific POSC/Caesar Reference Data Library, and the IFC Core Extensions. Similarly, concerning AEC/FM domain specific classes, co-ordination is necessary between national classification systems like BSAB 96, a future construction specific POSC/Caesar Reference Data Library and the IFC Interoperability classes.

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237 COST ESTIMATION OF HIGH PERFORMANCE CONCRETE (HPC) HIGH-RISE COMMERCIAL BUILDINGS BY NEURAL NETWORKS

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Abstract

Neural network approach is applied to establish relationships between the quantities/cost of the concrete/formwork, which is required for the structural elements of tall buildings using high performance concrete (HPC), and the design variables. Hybrid and hierarchical strategies are proposed for the cost estimation, where the feed-forward networks are adopted. After training, the neural networks are utilized to predict automatically the quantities/cost of HPC wall-frame structures in tall commercial buildings. Verifications are conducted with respect to various sets of the design parameters and a comprehensive discussion is given.

Keywords: High performance concrete, cost estimation, high-rise buildings, neural networks

1 Introduction

The costs of the high strength concrete (HSC) building structures are influenced by a number of factors, including the structure parameters (e.g., the grid size, the number of story and the grade of concrete), the building design specifications (e.g., the lateral drift of the building structure) and the design objectives (e.g., the minimization of total weights). Consequently, developing a model for cost estimation requires an intensive understanding of the relations between the above factors and the costs. Traditional approaches to cost estimation are mainly based on spreadsheets, database management systems (Bett, 1987), statistics (Wilson, 1982; Singh, 1994), linear regression (Koushoulas and Koehn, 1974; McCaffer, 1976; Bowen, 1985;

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Singh, 1990). These methods are not appropriate for nonlinear multi-dimensional relationships involved in the cost analysis. Developing empirical or semi-empirical formulae through either simulated database (Singh, 1990, 1994) or the practical statistics (Karsheras, 1984) for the cost estimation of building structures is extremely difficult because of the highly coupled interaction among various factors.

Application of neural network approach to construction is a relatively new research area, including the modular construction decision making processes (Murtaza et al., 1994), construction cost estimation (Li, 1995a, 1995b), construction management (Chao and Skibniewski, 1994; Boussanaine, 1995; Li, Zeng and Guan, 1996), construction optimization (Flood and Kartam, 1994), construction bidding and forecasting (Gaarslev, 1991; McKim, 1993). In the development of neural cost models, Li (1995a, 1995b) explored the effect of network configuration on the accuracy of the models and discussed the difficulties in use of neural networks. The data for training the network was sampled from a bidding game. For predicting strength and workability properties of the fibre reinforced concrete (FRC) mixes, the feed-forward neural network has been employed (Rao, 1997), where the relations between the water-cement ratio, aggregate-cement ratio, aspect ratio and volume percentage of fibres, and the various strength parameters are learned. Hua (1996) applied neural network to forecast the demand for residential construction in Singapore, where a total of 12 economic indicators are identified as significantly related to demand for residential construction. It has been found that the neural network model can produce a better prediction than the conventional multiple regression.

In this paper artificial neural networks are applied to establish relationships between quantities/costs of the concrete/formwork for structural elements of tall buildings using high strength concrete and the design parameters. Two neural strategies of the cost estimation are proposed while the feed-forward neural networks are adopted. The trained networks are utilized to predict automatically the quantities/costs of high performance concrete (HPC) structures in tall buildings. Verifications are conducted and comparative analysis is given.

2 Neural cost estimation strategy

2.1 Problem of the cost estimation

The costs of concrete and formwork are directly proportional to their quantities required. The quantities are, however, affected by the structural design parameters such as grid sizes, grades of concrete, and numbers of stories. These costs and quantities can be found by using a structural design software package and computer calculation when the shape of the structure and its structural form are defined. In Hong Kong, the most common type of structural form for tall commercial buildings is the "Wall-Frame" structure which uses the shear wall construction to resist the lateral wind load and provides a centrally located service core to house utilities such as lifts, toilets and stairwells.

In this study, neural networks are anticipated to model the quantities/costs of concrete and formwork required for the building structures, enabling designers to be aware of the design economy in adopting various design parameters such as concrete grades, grid sizes and numbers of stories. Direct collection of the cost data from practical statistics imposes some difficulties: expensive, time consuming and uncertain. The simulation approach is thus developed, by means of several software packages including TBCAD, ETABS, optimal drift design codes (Fig. 1), for generating the database for cost estimation. The wall-frame structure, as shown in Fig. 2(a), is assumed for tall commercial buildings of 40 to 70 stories in this study, because it is the most common form of structure for tall buildings in Hong Kong. The fundamental structure members in the wall-frame structure systems involve solid slabs, beams, columns and shear walls. The simulation is based on the structural floor plan shown in Fig. 2(b). The whole structure is supposed to be constructed by HPC.

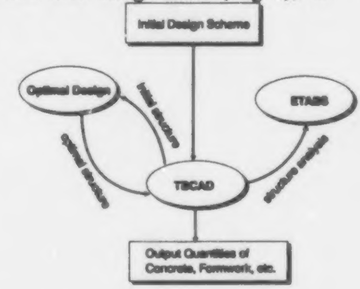


Fig. 1: Sampling scheme of the database for cost estimation

2.2 Hybrid cost estimation

Given a set of input variables including the grid size, the number of story, the grade of concrete, one neural network can be used to estimate the costs for the concrete or formwork required for the structural elements (including the slabs, columns, beams and shear walls) and the whole structure. Fig. 3 presents this network-based hybrid model for cost estimation, where the network serves as a physical mapping between the input (independent) variables and the output (dependent) variables. However, the network may not be best suited to this multi-dimensional cost estimation problem, since the cost components to be estimated may have different sensitivities and variations with the input variables. Thus, the hybrid estimation model usually gives a compromised performance, although the training and implementation of the network require less computation.

2.3 Hierarchical cost estimation

The three inputs in the cost model above can also be decomposed by discretizing one or two independent variables into auxiliary variables. As such, the cost estimation can be carried out separately by a set of independent networks, leading to a hierarchical cost estimation scheme. Since networks are used to map relatively simpler input-output relationships, more suitable network configuration and learning parameters can be obtained and thus a better estimation performance can be attained.

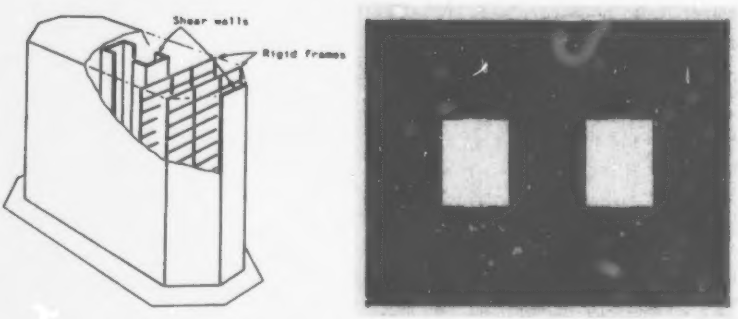
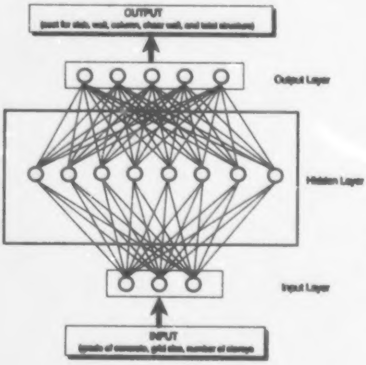


Fig. 2: Wall-frame structure and typical floor plan


OUTPUT
(cost for slab, wall, column, shear wall, and total structure)
Output Layer
Hidden Layer
Input Layer
INPUT

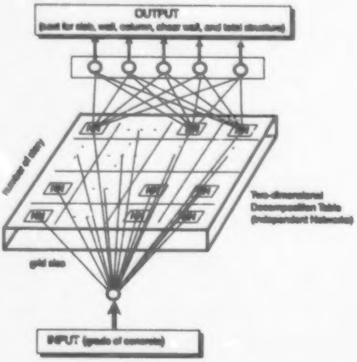


Fig. 3: Hybrid neural cost estimation (Model I)

Fig. 4: Hierarchical neural cost estimation (Model II)

When two input variables are discretized into auxiliary variables, the cost model has only one independent variable. Given a pair of auxiliary variables, say the grid size and the number of story, a simple network with one input (the grade of concrete) can be employed to estimate the cost for the concrete and formwork, as shown in Fig. 4. Thus, a serious of networks are required to cover entire ranges of the two auxiliary variables, with one network for each pair of the discretized variables. When another independent variable, say the grid size or the number of story, is selected, the network-based model similar to one shown in Fig. 4 can be applied.

When one independent variable is discretized into auxiliary variable, a network having two inputs can be used to estimate the cost for the concrete and formwork. With different variable as the auxiliary input, three hierarchical neural models can be developed. Fig. 5 shows the hierarchical models for the costs with the number of story. In such models, a number of networks are needed to estimate the cost with respect to a particular discretized auxiliary variable. Each network has to be trained and applied independently.

3 Network construction and training

With respect to the hybrid model (Fig. 3), the input layer of the network has three neurons representing the grid size, the number of story and the grade of concrete, respectively, while the output layer has a total of five neurons representing the quantities of the concrete and the formwork for the slabs, columns, beams, shear walls and the whole structure. For the hierarchical models (Fig. 4 and 5), the inputs to the particular network depend upon the estimation scheme, while the outputs are the same as those for the hybrid model. There are one or two inputs when two or one input variables are discretized into auxiliary variables, respectively. As regards the number of hidden layers and neurons in each hidden layer, there is no general guideline for their selection. Associated with the hidden and output neurons are binary sigmoid transfer functions.

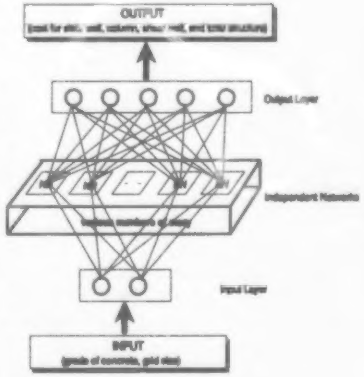

OUTPUT
(cost for slab, wall, column, shear wall, and total structure)
Output Layer
Independent Networks
Input Layer
INPUT
(grade of concrete, grid size)

Fig. 5: Hierarchical neural cost estimation (Model III) (with the number of story as the auxiliary)

The feed-forward network is used to establish in an implicit manner the complex multi-dimensional mapping between the inputs and the outputs. Network training is to adjust the network weights to learn the training patterns, which is conducted by a commercial software NeuralWorks[*] in this study. After training, the network can be instantly converted into a callable function for further implementation in the hybrid and hierarchical strategies.

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[*] The NeuralWorks is a product of NeuralWare, Inc., Pittsburg, PA 15276, USA.

4 Results and discussion

4.1 The training and testing patterns

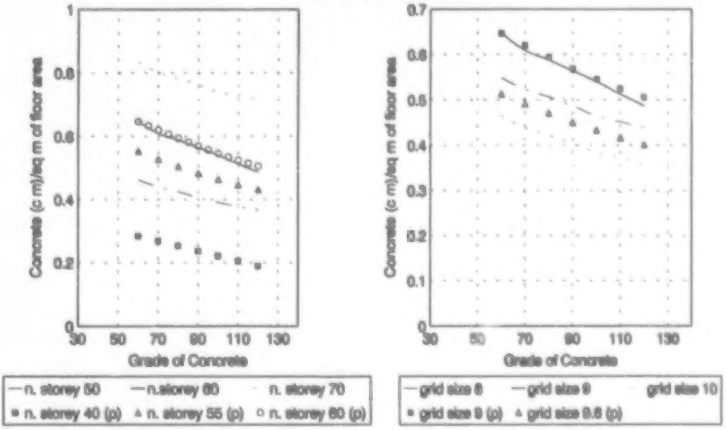
The major objective of this investigation is to develop the neural network-based cost models, to realize the automatic cost estimation. To have such models, it is required to develop a comprehensive set of samples which cover ranges of independent variables influencing the cost of the HPC building structures. This is achieved in this study by conducting simulation experiments via the scheme shown in Fig. 1. The output obtained from the experimental simulations includes the quantities/costs for slabs, beams, columns, shear walls and the whole structure which are used as the desired target output for training the neural networks. The grade of concrete, the grid size, the number of story are chosen to be independent variables and sampled in ranges of (60-120MPa), (4-12m) and (30-70), respectively. Table 1 gives the quantities for the concrete of the structural elements, while the data for the formwork is omitted. There are a total of 9x5x7=315 training pairs.

Table 1 Training patterns for the networks for cost estimation of the concrete

Input Patterns			Desired Output Patterns			
Grid Size (m)	Number of Story	Grade of Concrete (MPa)	Slab (cu m / sq m floor area)	Column (cu m / sq m floor area)	Beam (cu m / sq m floor area)	Wall (cu m / sq m floor area)
:::	:::	:::	:::	:::	:::	:::
6	30	70	0.085896	0.030381	0.023374	0.060371
6	30	80	0.086041	0.023675	0.021465	0.054709
6	30	90	0.086260	0.019977	0.012665	0.050393
6	30	100	0.08649	0.017713	0.011579	0.043801
6	30	110	0.086569	0.009452	0.005277	0.038136
6	30	120	0.08662	0.006741	0.004915	0.034264
:::	:::	:::	:::	:::	:::	:::
12	70	60	0.083870	0.128454	0.017954	0.151222
12	70	70	0.084042	0.108113	0.016845	0.143726
12	70	80	0.08416	0.098742	0.015910	0.138567
12	70	90	0.084322	0.094112	0.014956	0.132635
12	70	100	0.084417	0.086002	0.014082	0.124727
12	70	110	0.08463	0.082804	0.013213	0.119628
12	70	120	0.084789	0.078963	0.012369	0.116040

4.2 Results for hybrid cost estimation (Model I)

After a number of trial runs, it has been found that the network of two hidden layers, having 10 neurons each, can achieve a better training performance of the converging error of 0.08. Hence, such a network is finalized for the hybrid cost model. The validation and testing results are plotted in Fig. 6, with respect to various combinations of the grid size, the number of story and the grade of concrete. Fig. 6(a) shows the estimated cost of the whole concrete, for the numbers of story of 40, 55 and 60, varying with the grade of concrete, given a fixed grid size of 9m. The estimated costs for the number of story of 60 is found to agree uniformly with the desired ones. The estimated costs for the number of story of 55 have clear reasonable trends of variations and are well interpolated. Fig. 6(b) presents the validation results for the grid sizes of 9m and 9.6m with respect to different grades of concrete, given the number of story of 60. Satisfactory agreement of the estimated costs with the desired ones and excellent interpolation of the neural estimation have been confirmed.



(a) (b)

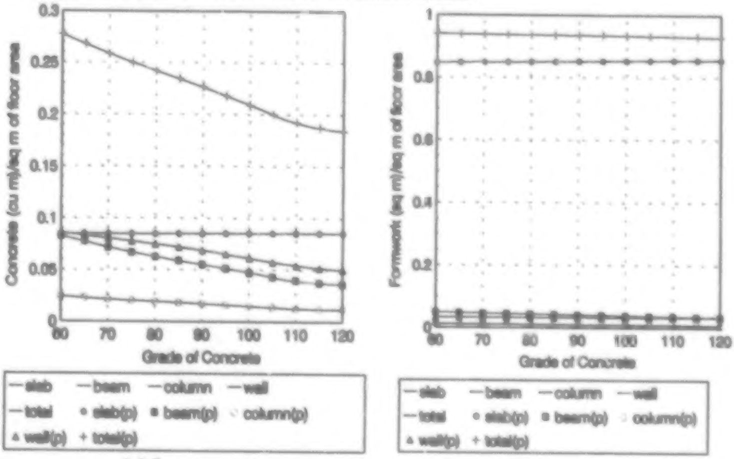
Fig. 6: Validation results for hybrid cost estimation (Model I) for the concrete

4.3 Results for hierarchical cost estimation (Model II)

With respect to the estimation model (Fig. 4), a number of networks are required for different pairs of auxiliary variables. In this work only one network for the particular grid size of 9m and number of story of 40 is given as an example. For this model there are one input and five outputs. After numerous trial runs, the network configuration of one hidden layer with five neurons has been adopted, with the converging error of 0.02. The validation results for the costs of the concrete and the formwork are presented in Fig. 7. The promising estimations have been found.

4.4 Results for hierarchical cost estimation (Model III)

When the number of story is taken as auxiliary variable, the hierarchical strategy can be realized using the Model III (Fig. 5). A number of networks with two inputs and five outputs are required to estimate the costs for concrete and formwork, with one network for each fixed number of story. In this case, there are a total of 9x7=63 training patters, with respect to the grid sizes of 4, 5, ... and 12, and the grades of concrete of 60, 70, ..., 110 and 120. The network configuration of two hidden layers with 10 neurons each has been adopted after a few of trial runs. The converging errors are about 0.01 and 0.02 for the networks for the concrete and formwork, respectively. Fig. 8 shows the validation results for the cost of the total concrete and formwork, for the discretized number of story of 60, with respect to various grades of concrete. The estimation has been found excellent for the costs of the whole structure concrete. The estimated costs for the grid size of 9m fall uniformly on the curve for the desired costs. The estimated costs for 9.6m look well interpolated between the curves for both grid sizes of 9m and 10m. However, the errors associated with the estimated costs for the total formwork look quite larger. The desired variation of the cost in the range of the grades of the concrete of 60MPa and 80MPa has been smoothed off in the neural model.



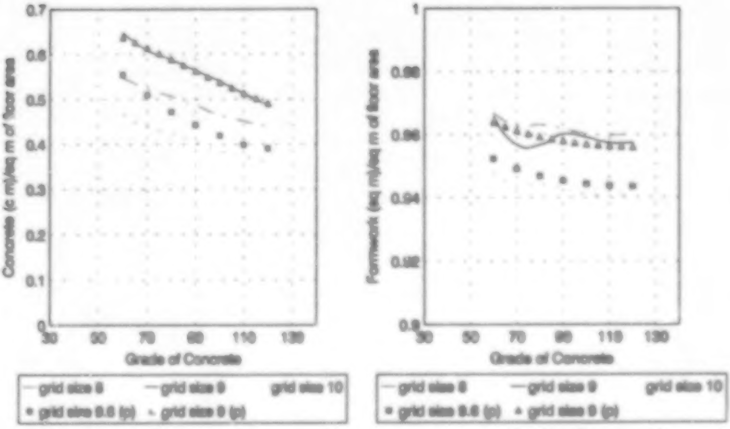
(a) for concrete **(b) for formwork**

Fig. 7: Validation results for the cost estimation (Model II)

4.5 Comparative analysis

Adopting the hybrid estimation strategy, only one neural network is required and trained. It has been confirmed from the training results that the network (for both concrete and formwork) has the best converging accuracy of 92%, which is smaller than the training results of the hierarchical strategy. The major advantage of the hybrid strategy for the cost estimation is easy to implement. Thus, if the average estimation error of 0.08 is acceptable, the estimation strategy is suggested.

For achieving a better estimation accuracy, the hierarchical strategy is suggested. The training as well as estimation performance of the hierarchical strategy varies from one model to another. It is found that the model II and model III give better estimation performance with accuracy of 0.01 and 0.02. However, as the hierarchical estimation strategy requires more than one network, more training and implementation work is necessary.



(a) for concrete (b) for formwork

Fig. 8: Validation results for the cost estimation Model III (with the number of story being auxiliary variable at 60)

5 Conclusion

Using the quantities/cost data for the structure elements generated from the structure analysis, neural networks can be employed to predict automatically the costs of concrete and formwork required for a wall-frame structure system of tall commercial buildings using high strength concrete. The structural elements involve solid slabs, beams, columns and shear walls. Design parameters such as grid sizes, numbers of story and grades of concrete have been considered in the models to assess their effect on quantities/costs of the HPC structures. Two strategies of cost estimation based on neural networks have been proposed. From the training and validation results, it can be concluded that all the neural models, no matter of the hybrid or hierarchical strategies, can provide a promising cost estimation. The two strategies are compared and it is confirmed that the hybrid model is less accurate but easy to be trained, while the hierarchical models are more accurate but more complicated in implementation.

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238 METAGAME ANALYSIS FOR DETERMINING CONSTRUCTION METHODS

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Abstract

This paper deals with the use of metagame analysis to help resolve conflicting factors affecting the choice of a reinforced concrete structural system. The most suitable construction method in a project varies in accordance with several factors, but may be limited to: overall construction cost, construction duration, quality of construction and effect of environmental issues. A computer program was developed as a tool to analyse the decision making process using an Analytical Hierarchy Process and is used to decipher different preferences based on prioritised objectives. The specific focus in this paper is resolving to choose pre-cast concrete in comparison to cast-in-place technology in a project operated by a firm including an owner, an architect and a construction manager. The results derived from the metagame analysis shows that the priority afforded to the various factors affecting a particular choice of building system is dependent upon the preference given to these factors and this necessarily will have an effect the manner in which the conflicting objectives are resolved.

Keywords: Building construction, construction method, decision-making, design build, metagame analysis, pre-cast concrete

1 Introduction

Pre-cast concrete technology was introduced into building construction in the 1960's and ultimately brought about significant changes to Japan's construction industry. However, its adoption did not advance smoothly and the many advantages that the use of pre-cast concrete potentially offers have not been realised in Japan. Indeed, the adoption of pre-cast concrete construction within the industry was

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hindered by a number of problems such as the lack of skilled and the age of labourers, the requirement to insure quality construction, the need to minimise the duration of construction and the use of material resources to name but a few of the evident contributing factors. One of the factors inhibiting its implementation was that firms, or those individuals involved in the construction process such as the owner, architect and contractor, did not always collaborate to adopt pre-cast concrete. This is because the individual "players" in the construction "game" often sought to capture an advantageous strategy for themselves, by which they would minimise their perceived risk. For example in a given project where pre-cast concrete might be considered as a potential option, a project architect may have insisted on flexibility of design whereas the construction managers' priority was to minimise the duration of construction. In such a case, the architect avoids pre-cast concrete though the construction manager suggests it. Hence, there exists a conflict problem that often in the past has been resolved simply by resorting to construction solutions that minimise the risk to the owner or the owners representative, i.e. the architect. This typically is what has occurred to hinder the adoption of pre-cast in the Japanese construction industry that is, as are many other such industries around the globe, essentially risk avers.

The purpose of this paper is to analyse such types of conflict using the metagame decision support method specifically to help clarify the adoption of pre-cast concrete. The decision support system metagame was first developed in the 1970s and has since been applied to resolve conflicts in many different kinds of engineering fields. However in the Japanese building construction industry its use as a project management tool is not well known. The conflict problem that required solving is the preference for cast-in-place concrete in relation to pre-cast concrete given their respective construction costs. The authors assessed the preference using quantitative methods offered in metagame; a computer program of the metagame analysis was developed to help resolve this problem.

2 Conflict problem

2.1 Overview

If one compares the pre-cast and cast-in-place concrete industries, one might suggest that comparison could be made on the basis of overall construction costs, duration of construction, quality of work offered by the finished product and effect on environment issues. In general, the cost of pre-cast concrete is reasonably stable as a typical manufacture of pre-cast concrete regularly produces multiple units of high quality concrete assemblies. In regards to transportation of pre-cast units, this usually tends to be left to a specific trader of which few changes in cost can be expected.

To the Japanese pre-cast concrete is suggestive of shabby, uniform and uninspired architecture. An owner's interest is focused not on the construction method but indeed, on the design, as well as the construction duration and cost. It is generally agreed in Japan that architect-designers believe the use of pre-cast concrete construction offers little planning flexibility. Furthermore, such designers often wish to adhere to quality in the design and therefore, they do not always encourage adoption of pre-cast concrete. However, it is noted that pre-cast concrete is used not only for structural members but also for non-structural members such as balconies. In such instances, the flexibility of the design can be guaranteed.

In the Japanese construction industry, cast-in-place concrete is easier to complete than pre-cast concrete structures. For the contractor, it is important to know how to build and to control the cost of construction. Therefore, pre-cast concrete systems do not tend to be adopted by contractors since wide spread knowledge of this technology does not exist. However, certain projects have been completed using this technique in instances where the quality of construction, durability and reduced construction schedules were important factors. The duration of construction of pre-cast concrete structures can be reduced, since the unit assemblies are first fabricated in a factory environment permitting strict control over fabrication schedules and the finished goods are thereafter transferred to the site in appropriate sequence thus minimise delays or scheduling problems. In general, the quality of pre-cast concrete material is essentially the same in comparison with cast-in-place concrete. However, pre-cast concrete assemblies are produced under precise production controls that assure high quality in concrete materials and highly accurate dimensions. Hence they are the preferred system in instances where these attributes are of importance.

Pre-cast concrete has obvious advantage in regards to environmental issues since its use minimises the use of tropical wood in the construction process (for formwork) and construction waste is likewise reduced using pre-cast thus mitigating the disposal problem.

2.2 Problem defined

The adoption of pre-cast concrete is the conflict problem being investigated. The conceptual model developed to study this problem is based on the following assumptions. An integrated construction company is to execute a turnkey building project using a reinforced concrete (RC) structural system; the company itself is an owner of the project. The conflict problem is whether to adopt pre-cast or cast-in-place concrete for the project. It is assumed here that the company has sufficient knowledge of pre-cast technology that this is not a hindrance to its being selected. Each department of the company is considered is a person involved in the problem.

3 Outline of metagame

3.1 Using metagame

When certain persons or firms are faced with conflict problems, the solution is often not easy to derive. Because an individual person or firm will act in their best interest it is not then always possible to reach the best agreement for others involved in the conflict. Metagame analysis is a process introduced to help resolve conflict problems in which the main focus is that of finding a stable state common to all persons or firms involved in the conflict (Okada; 1988).

3.2 Components of metagame

The main components of metagame consist of: players, options, scenarios, order of preference and stability analysis, each of which is briefly described below.

Players:	The persons or firms involved in a conflict problem.
Options:	Players act in this conflict problem through a process called an option. One or several options exist for each player.
Scenarios:	Each option is not mutually exclusive. The player can take some of those options at the same time. The combination of options of each player describes a specific plan. When an option is selected, the number '1' is assigned to the option. When an option is not selected, '0' is assigned. A scenario is defined as a row of values consisting of '1' or '0' for each option. It is necessary to select the scenarios that can exist and actually be executed (i.e. executable scenarios).
Order of preference:	Each player defines the order of preference among executable scenarios. It is an order of scenarios sorted by the preference that the player assesses among all executable scenarios.
Stability analysis:	Stability analysis is the process of searching for a solution. The state in which stability exists for all the players is the solution of the conflict problem.

3.3 Procedure for stability analysis

There are four steps in the stability analysis (Okada *et al.* 1988), each of which is described below:

Step 1	Preparation of the scenarios	All the executable scenarios may be the solution. Therefore, it is necessary to pick up all possible scenarios.
Step 2	Finding unilateral improvement	When a player intends to change their plan, the action that is in the direction where the order of the preference goes up by changing their option is called unilateral improvement (UI). In UI, only one player changes the option whereas other players do not change their options.
Step 3	Finding detrimental processes	Assume that player *A* moves to scenario *p* by UI from scenario *q*. If another player *B* moves to other scenario where the order of preference for player *A* falls, player *B* is regarded as being detrimental to player *A*.
Step 4	Finding stable scenario(s)	There are three results in the stability analysis: (1) Reasonable (r); (2) Sequentially stable (s); (3) Unreasonable (u) When there are no scenarios that become UI from a scenario, the scenario is regarded as reasonable. Not unreasonable scenario, (r) and (s), for all players are the solution of conflict problem.

4 Application

Definition of players in the project

The player who takes the part as:

- an owner – is the development department (OW);
- an architect – is the design department (AR);
- a contractor – is the construction department (GC).

Definition of options

The options are based on the strategy of each of the players as shown in Table1.

Definition of scenarios

If all the options are executed independently, the number of total scenarios is $2^5=32$. There exist within this set of possible scenarios a number of scenarios that cannot be executed. For example, two options of the AR are contradictory; hence in this case, the number of scenarios should be reduced to 16 as shown in Table 1.

4.1 Defining the order of preference using the analytical hierarchy process

The strategy of each player depends on their respective viewpoint regarding overall costs, construction duration, and quality of construction and environmental issues. The order of preference differs according to criteria the players use to assess the respective significance of each factor. For example, the criteria for the OW (owner-development department) are cost, duration, quality and environment as shown in Table 2(a). Likewise, the criteria for the AR (architect-design department) are cost, duration, and quality, as shown in Table 2(b). Finally, The criteria established for GC (contractor-construction department) are cost, duration, and environment, as shown in Table 2(c).

Three cases (a, b, c), representative of combined criteria of the three players acting in concert, are the basis for analysis using the metagame method; these combinations are provided in Table 3. Case (a) shows the requirement for cost reduction. Case (b) is an often-expressed pattern in construction projects, i.e.; it is the situation where the AR (architect-design department) gives priority to quality. Case (c) is the typical situation in which the OW (owner-development department) and the GC (contractor-construction department) focus on an effective sales strategy and hence may be intent on minimising the construction duration.

The Analytical Hierarchy Process (AHP) is used for defining the order of preference by calculating an integrated degree of worth of the various options. In AHP, the criteria are compared in pairs and the evaluation of superiority or inferiority of each set is given subjectively in five stages. The qualitative relations among the criteria can be obtained by calculating the geometric average. The correspondence of the evaluation is assessed according to a consistency index (CI). Here it is assumed that if CI is 0.1 or less, it is appropriate to use the model.

Table 1: Scenarios of the conflict problem

Scenario Number	OW	AR		GC	
	Permitting Cost increase	Using cast-in-place Concrete	Using PCa	Hiring more staffs	Using more materials And equipments
1	1	1	0	1	1
2	1	1	0	1	0
3	1	1	0	0	1
4	1	1	0	0	0
5	1	0	1	1	1
6	1	0	1	1	0
7	1	0	1	0	1
8	1	0	1	0	0
9	1	1	0	1	1
10	1	1	0	1	0
11	1	1	0	0	1
12	1	1	0	0	0
13	1	0	1	1	1
14	1	0	1	1	0
15	1	0	1	0	1
16	1	0	1	0	0

In AHP, the sum of the respective degrees of worth is 1.0. In this case, as there are 5 options, their average is 0.2. It is assumed that an undesirable option for a player is one for which the degree of worth falls below 0.2 (i.e. below the average). Values above 0.2 are subtracted from original degree of worth are shown in Table 2. For example, in Table 2(a), for OW, the value of "duration" is as follows: "permitting cost increase":-0.054; "using cast-in-place concrete": -0.09; "using pre-cast concrete"; 0.310; "hiring more staffs"; -0.058; and, "using more materials and equipment":-0.117.

The score for each scenario is determined in the following manner: assume the degree of worth of each option is given by (*A, B, C, D, E*); selection of each option (1 or 0) is given by (*a, b, c, d, e*); and, the point of scenario *j* is *P(j)*. Then *P(j)* is:

$$P(j) = Aa + Bb + Cc + Dd + Ee \tag{1}$$

All the scenarios are sorted by the order of preference as shown in Table 4.

4.2 Stability analysis

The results of metagame analysis are shown in Table 5. Case (a) is explained in detail below. Scenario 1 for the OW (owner-development department) is the initial item discussed. The OW moves to scenario 9 as a one-sided improvement from scenario 1. On the other hand, there is no one-sided improvement of the AR (architect-design department). The one-sided improvement of the GC (contractor-construction department) is found in scenarios 10, 11 and 12. Here, the order of preference of scenarios 10, 11 and 12 is higher than that of scenario 1 for the OW. Hence this scenario is not detrimental to the OW. Therefore, scenario 1 becomes unreasonable (u) for the OW. Likewise, scenarios 2 to 8 are also unreasonable for the OW.

Next, the stability of scenario 9 of the OW is analysed. A review of scenario 9 shows that the OW does not have a one-sided improvement therefore, scenario 9 is reasonable (r) for the OW. In the same way, scenarios 10 to 16 are also reasonable (r) for the OW.

Results from the analysis show that scenarios 1 to 4 and scenario 9 to 12 of the AR (architect-design department) do not have a one-sided improvement hence, they are reasonable (r). Scenario 5 of the AR moves to scenario 1 by a one-sided improvement. On the other hand, the OW moves to scenario 9 by a one-sided improvement. As for scenario 9, the order of the preference is lower for the AR than that of scenario 5. Therefore, scenario 5 is stable (s) for the AR. Scenarios 6 to 8 are similarly stable for the AR. The AR moves from scenario 13 to scenario 9 by a one-sided improvement. On the other hand, the OW has no one-sided improvement, and the GC moves to scenarios 10, 11 and 12 by a one-sided improvement. There is no one-sided improvement from there for the OW either. The order of the preference of scenarios 10, 11 and 12 is higher for the AR than that of scenario 13. Therefore, scenario 13 is unreasonable (u) for the AR. Scenarios 14 to 16 are similarly unreasonable for the AR. So the balanced solution is scenario 12, "Conventional industrial method design" in Case (a).

Table 2: Degree of worth of each option

Criteria	Permitting Cost increase	Using cast-in-place Concrete	Using PCa	Hiring more staffs	Using more materials And equipments
(a) Development department (OW)					
Cost	-0.105	0.216	0.032	-0.013	-0.139
Duration	-0.054	-0.090	0.310	-0.058	-0.117
Quality	-0.016	-0.106	0.313	-0.077	-0.123
Environment	0.039	-0.078	0.226	-0.064	-0.127
(b) Design department					
Cost	0.077	0.050	-0.014	-0.048	-0.064
Duration	-0.036	-0.107	0.185	0.005	-0.047
Quality	-0.025	-0.076	0.130	-0.020	-0.003
(c) Construction department					
Cost	0.261	0.003	-0.095	-0.049	-0.127
Duration	0.135	-0.129	0.083	0.004	-0.094
Environment	0.215	-0.129	0.063	-0.036	-0.114

Table 3: Criteria each player gives priority

Case	Criterion of each player		
Name	OW	AR	GC
(a)	Cost	Cost	Cost
(b)	Cost	Quality	Cost
(c)	Duration	Cost	Duration

Table 4: Scenarios sorted by the order of preference

Order of Preference	OW				AR			GC		
	Cost	Duration	Quality	Environment	Cost	Duration	Quality	Cost	Duration	Environmen
1	12	16	16	8	4	14	16	4	8	6
2	10	8	8	16	2	16	15	2	6	8
3	4	14	14	6	8	13	14	8	7	5
4	2	6	6	14	3	15	13	3	5	7
5	11	15	15	7	12	6	8	6	4	14
6	9	7	7	15	6	8	7	1	16	16
7	16	13	13	5	1	5	6	7	2	2
8	14	5	5	13	10	7	5	12	14	4
9	3	12	12	4	7	10	12	5	3	13
10	1	4	4	12	16	12	11	10	15	15
11	8	10	10	2	11	9	10	16	1	1
12	6	2	2	10	5	11	9	11	13	3
13	15	11	11	3	14	2	4	14	12	10
14	13	3	3	11	9	4	3	9	10	12
15	7	9	9	1	15	1	2	15	11	9
16	5	1	1	9	13	3	1	13	9	11

Table 5: Result of stability analysis

Scenario Number	Case (a)			Case (b)			Case (c)		
	OW	AR	GC	OW	AR	GC	OW	AR	GC
1	u	r	s	s	u	s	u	r	s
2	u	r	s	s	u	s	u	r	s
3	u	r	s	s	u	s	u	r	s
4	u	r	r	s	u	r	u	r	r
5	u	s	s	u	r	s	s	s	s
6	u	s	s	u	r	s	s	s	s
7	u	s	s	u	r	s	s	s	s
8	u	s	r	u	r	r	s	s	r
9	r	r	u	r	u	s	r	r	u
10	r	r	u	r	u	s	r	r	u
11	r	r	u	r	u	s	r	r	u
12	r	r	r	r	u	r	r	r	r
13	r	u	u	r	r	u	r	u	s
14	r	u	u	r	r	u	r	u	s
15	r	u	u	r	r	u	r	u	s
16	r	u	r	r	r	r	r	u	r

The computer program was developed to automatically analyse the stability of the conflict problem for each player when the order of preference within a given scenario given. The GC (contractor-construction department) moves from scenario 1 to scenarios 2, 3 and 4 by a one-sided improvement. The AR has no one-sided improvement from them, and the OW moves to scenarios 10, 11 and 12 by a one-sided improvement. As the order of preference of those scenarios is lower than that of scenario 1 for an architectural department, scenario 1 is a stable (s) for the GC. Scenarios 2, 3, 5, 6 and 7 are similarly stable. The GC moves from scenario 9 to scenarios 10, 11 and 12 by a one-sided improvement. Because neither the OW nor the AR has a one-sided improvement from there, scenario 9 is unreasonable (u). Scenario 10 and 11 are also unreasonable. The GC moves from scenario 13 to scenarios 14, 15 and 16 by a one-sided improvement. Only the AR has a one-sided improvement from there to scenarios 10, 11 and 12. As for scenarios 10, 11 and 12, the order of preference is higher than that of scenario 13 for the GC. Therefore, scenario 13 is unreasonable (u) for the GC. Scenario 14 and 15 are also unreasonable. Because the GC does not have a one-sided improvement from scenarios 4, 8, 12 and 16, these scenarios are reasonable (r).

5 Discussion

The result of the analysis of the three cases shows the following features:

Case (a) — Where the players prioritise cost as the significant parameter, "conventional industrial design" offers the balanced solution. Hence in such situations, the adoption of the pre-cast concrete method is shown to be difficult. In this case, the conventional method is preferred where the cost reduction is the main criterion as it currently exists in the construction industry.

Case (b) — When the AR (architect-design department) gives priority to quality, the order of the preference of the scenarios changes towards adopting the pre-cast concrete method; indeed, the balanced solution moves to the "Pre-cast concrete method".

Case (c) — for this case, five balanced solutions exist. However, the balanced solution that is chosen as the preferred one is not obtained from metagame analysis. Here, the most preferred solution is obtained from multiple balanced solutions by the method described below.

The one scenario in which all players are most balanced in the state of stability should first be determined from which "harmony" score of the given scenario is thereafter calculated by applying AHP. The "harmony" score for the scenario is determined for each of the 3 players, and superiority or inferiority is evaluated depending on the degree of "harmony".

For example, the total score of the 3 players was calculated in Case (c). The harmony score level becomes scenario 8, i.e., "Full pre-cast concrete design by which the OW admitted an increase in the cost of construction", and continues with scenario 6, 7, 5, and finally, scenario 12. Even in the same balanced solution, the order can be determined by evaluating the sum of the scores for the 3 players.

The method differs according to the problem and depends on the judgement of the metagame analyst. The analysis using the above-mentioned method shows that:

- If the combination of elements to which each player gives priority changes, the balanced solution is also different.
- The intention of the AR (architect-design department) greatly influences in the range of the cases treated here.

6 Conclusions

The difference in preferences of individual players in regards to the pre-cast concrete method was modelled as a conflict problem among three players in an integrated construction firm: the owner (OW), the AR (architect-design department) and the GC (general contractor). The metagame decision making method was used to analyse these preferences and provide a means to examine the outcomes of the decision making process.

The order of preference of the respective players in regards to overall construction cost, duration of construction, quality of work and environmental issues was assigned and their respective priorities determined. The player who had the most significant influence on the decision process based on the chosen combinations, preferences and priorities was examined. Results show that a balanced solution to resolve the conflict problem varies in accordance with the factor to which the players gave priority. Although in this paper the number of players was restricted to three, there are likely to be a number of additional players in a real project; e.g., specialist contractors and pre-cast concrete material suppliers would, most likely, also take part. And it is also necessary to review in greater detail the pre-cast concrete option in regards to both the promotion and obstruction factors and in relation to actual conditions in the field. This should be taken into consideration in future work.

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239 CONSTRUCTABILITY KNOWLEDGE-INTENSIVE DATABASE SYSTEM

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Abstract

Generally, lessons learned in the construction, operation, and maintenance of a facility are not effectively fed back as input to the design and construction phases of new projects. Traditional methods of collecting and disseminating lessons-learned in the construction of projects have enjoyed limited success due to: (1) the unreliable communication channels between construction experts and practitioners, (2) the lack of a meaningful classification system, (3) the unmanageable format that made it difficult to access, retrieve and update the potentially enormous volume of lessons, (4) the difficulty of integrating new systems into existing operations and procedures, and (5) the focus on failures or incidents, rather than on both positive and negative experiences with constructed facilities. If the experience and lessons learned at the construction site could be captured and incorporated into a dynamic, interactive, knowledge based information system, then great benefits could be realized as this information is utilized in the design and construction of future facilities. Constructability and maintainability can be enhanced, more efficient construction methods can be utilized, facility quality and safety can be maximized and total life cycle costs can be minimized.

This paper presents a knowledge-intensive database system for constructability improvement. Construction lessons were collected; a framework for classifying, storing and disseminating lessons was designed; and a prototype system was developed, tested and validated. This system can be used: (1) as an assistant and decision-making tool by engineers and foremen of contractors, and (2) as an educational and training tool by undergraduate and graduate students of civil engineering at Kuwait University.

Keywords: Constructability, value engineering, lesson learned, feedback system, database

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1 Introduction

Each failure or nonperformance of a material, system, etc. can contribute to the advancement of engineering and construction management; just as every medical *post mortem* can contribute to the advancement of medicine. The problem in the past has been the establishment of a system to perform *post mortem* analyses and diffuse the knowledge gained. Medical doctors use a system called *Medlars*, and lawyers use a system called *WestLaw*. Unfortunately, no such system is available to construction companies, though construction is the largest industry in most countries.

Valuable information on the design, construction, operation, and maintenance of facilities is gained each working day. The problem has been the lack of a format for capturing and retrieving that information for use at some future date. The standard practice has been to depend on personnel who, through years of experience, know what happened and what was learned as a result. This information abruptly comes to an end when the experienced personnel are no longer available. In addition, failures and service interruption need quick and efficient solutions, both in time and money. The quick and easy access to a "lessons learned" feedback system will allow this in an interactive, proactive, and efficient manner.

While past efforts have focused on the design phase, opportunities for collection and dissemination exist in all phases of the facility life-cycle. Without making use of construction lessons learned, mistakes will be repeated; resulting in an increase in the overall construction cost due to repair, rework, construction failures, claims, poor reputations, etc. One study of industrial-type projects showed direct costs for construction rework at greater than 12% of the total project costs (Ledbetter 1989).

The Constructability Task Force of the Construction Industry Institute (CII) describes constructability as:

> "the optimum use of construction knowledge and experience in planning, engineering, procurement, and field operation to achieve overall project objectives." (CII 1987)

Similar to improving constructability during planning and design stages, the key to improving constructability during the construction phase is a formalized feedback system for construction knowledge (Kartam 1997). When a project has moved into construction, the feedback needed relevant to the tasks at hand primarily includes specific construction knowledge, e.g., methods, materials, equipment, and coordination. This type of input will influence the construction phase of the project with respect to duration, efficiency, and contractor profit.

2 Feedback in the project life cycle

The traditional life cycle of a project typically includes the following phases: conceptual planning and feasibility studies, design and engineering, construction, and operation and maintenance. Lessons learned from constructed facilities may have their genesis in any phase of a project's life cycle. Similarly, these lessons may be applicable in one or more phases of the project life cycle.

The various sources and uses of engineering-construction knowledge are depicted in Figure 1. Three feedback loops exist in a project life cycle; these include: value engineering, constructability, and post occupancy evaluation.

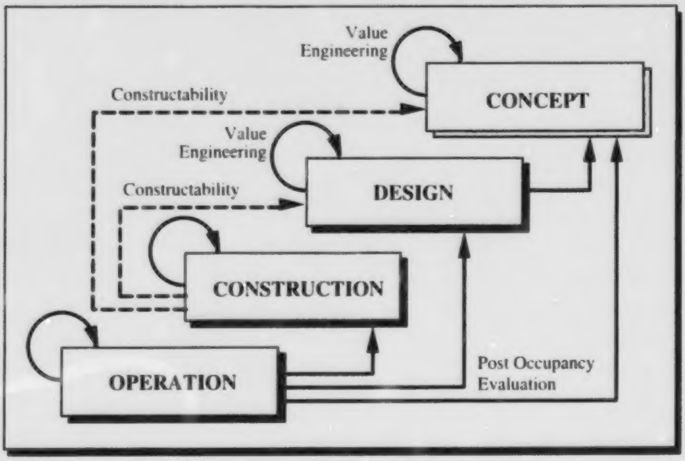


Fig. 1: Feedback channels in the project life cycle

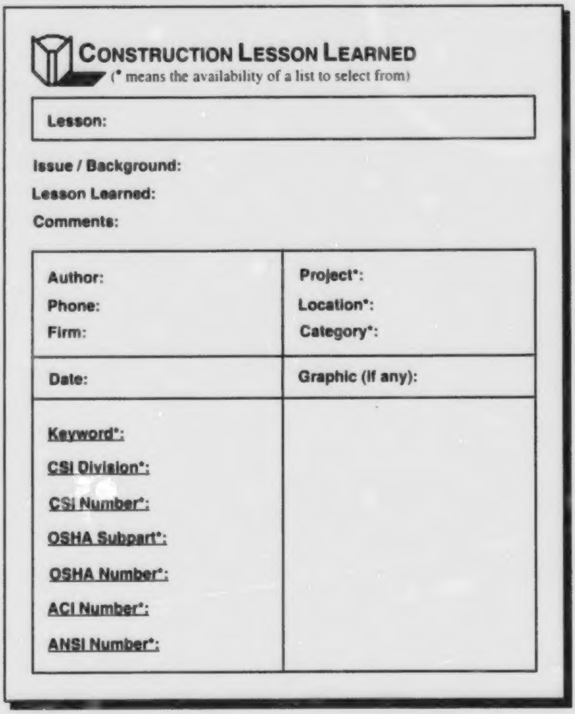
3 Research objectives

The overall objective of this project is to design and develop a constructability management information system for construction lessons learned. The specific objectives are: (1) collect expert knowledge and lessons learned to perform concrete construction operations, (2) design a framework for storing and disseminating construction lessons learned, and (3) implement a knowledge-intensive database system for applying these lessons in the construction of future facilities.

Below, two important issues in the development of the Constructability System are discussed: (1) a manageable format for organizing, storing, retrieving, and updating information, i.e., modeling, and (2) an effective mechanism for collecting, verifying, categorizing, and storing information, i.e., knowledge acquisition and knowledge engineering.

4 Modeling constructability knowledge

Because the type of information needed to properly document a construction lesson learned can take any shape; a simple, comprehensive, and flexible framework is needed. After reviewing previously attempted feedback systems, three major components of a lesson learned emerge (see Figure 2). First, a set of attributes necessary to sufficiently describe and explain the lesson itself. A lesson title, a description of the problem or situation, a description of the solution or method, additional comments, and perhaps a relevant sketch or reference to other documented information may be sufficient to describe a construction lesson. Second, information regarding the source and context from which the lesson is collected is necessary. The final component of a lesson learned involves the means for classifying the lesson in a manner that allows fast, clear retrieval by multiple parameters. A classification system is needed that will enable a user (expending minimal effort and from various perspectives) to quickly review selected, relevant lessons from the knowledge base. If the classification system is too general with categories that are too broad, lessons will be easily classified, but relatively impossible to effectively retrieve because of the inability to sufficiently narrow the scope of a search query. If the classification system is too specific with excessive categories, selecting between available categories becomes onerous.



CONSTRUCTION LESSON LEARNED
(* means the availability of a list to select from)

Lesson:

Issue / Background:
Lesson Learned:
Comments:

Author:
Phone:
Firm:
Project*:
Location*:
Category*:

Date:
Graphic (If any):

Keyword*:
CSI Division*:
CSI Number*:
OSHA Subpart*:
OSHA Number*:
ACI Number*:
ANSI Number*:

Fig. 2: The format of a constructability lesson learned

In the Constructability System, the lessons were analyzed and classified into the 16 divisions of the MASTERFORMAT system (CSI 1995), a widely used coding system in building construction in North America. The use of a common coding system improves consistency and information flow between the Constructability System and other computer-based construction systems allowing for better integration of organizational efforts. This is based on Construction Specifications Institute's (CSI) broad, medium, and narrow scope approach to classifying construction activities. Code extensions can be added to the basic CSI codes to indicate more specific information such as location of work or responsible organization.

Although the CSI system is the main coding and classification system which was adopted in the Constructability System, alternative means of information access and multiple views of the database are available, e.g., key words, structural component, construction activity, American Concrete Institute (ACI), American National Standards Institute (ANSI) and Occupational Safety and Heath Administration (OSHA) codes (see Figure 3).

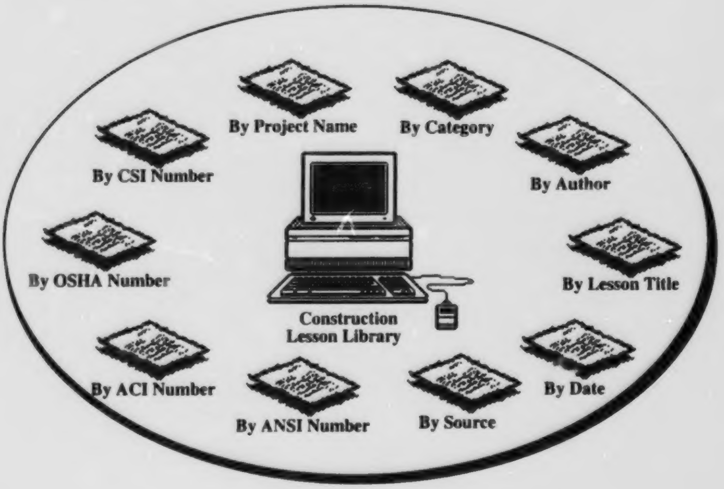


Fig. 3: Multi-classification approach for the constructability system

This system accommodates classification of many construction lessons, including those which involve the interface of two or more CSI categories. For example, a lesson involving space conflicts between electrical conduit and reinforcing steel within a concrete column could be classified under a CSI electrical category (16050), under a CSI concrete category (03200), under the component entitled "column", and perhaps under the keyword "space conflict". Keyword and component libraries were developed so that terms can be applied consistently.

Additional information that can be linked to the source project (e.g., concrete frame building, location, etc.) or source person (e.g., assistant superintendent) can be used as additional parameters in information retrieval. Lessons could also be categorized by individual contractor's "chart of cost" accounts, a method that may have more appeal with certain groups within organizations, as well as with contractors who work in sectors of the industry where CSI classification is not widely used.

5 Constructability knowledge acquisition

Extracting expert knowledge from subject matter, or domain experts is perhaps the most difficult step in the development of any knowledge base. *"Knowledge acquisition has been reported as the major bottleneck in the development of expert systems"* (Bowen 1990). In the construction arena, solid lessons are very difficult to extract (Fischer 1991). Consequently, few construction lessons learned have been documented. Successful project managers and superintendents have developed individual methods and procedures, proven effective by their longevity in this highly competitive market. Achieving a consensus when attempting to compile information on the best methods or procedures is difficult, further complicating the knowledge acquisition and validation process.

Experience in knowledge engineering has shown that personal interviews, rather than pure questionnaires, is the most effective method of knowledge acquisition. The interview process itself is critical to gaining an understanding of how successful project superintendents approach their business. It allows insight as to how they categorize, organize and utilize their rich experience. Heuristics, or rules of thumb, are plentiful in construction but difficult to articulate.

Interviews, with the main focus on concrete and site works in building construction, were conducted with more than fifty construction experts, including project executives, project managers, estimators, superintendents, field engineers, and foremen. Due to their hectic, unpredictable schedules, initial interviews were conducted by simply spending the day following superintendents around job sites. As areas of personal expertise became apparent, further questioning in those areas was pursued. Daily project dilemmas provided other opportunities to gain insight into frequently applied heuristics and problem-solving techniques. It was immediately apparent that extraction of valuable lessons requires much patience and persistence.

Decisions about information or lessons to be included in the system are not clear cut. Any lesson learned regarding the construction of a project is a viable candidate provided the lesson is based on acquired construction knowledge and is not merely common sense. Once the appropriate level of knowledge is decided upon, the process of collecting, classifying, and disseminating the information becomes essential. Because unique, universally-accepted solutions to any construction predicament are not common, alternative solutions, wherever they exist have been included.

6 System implementation and operation

The system was developed using a relational database management system MS-Access™ and hypermedia techniques running on IBM-PC class of computers. Combining the capabilities of database with hypermedia techniques allows alternative means of accessing information as well as potential integration with other computer-based construction systems. Hypermedia techniques permit dynamic linkage of separate text or graphic files or other forms of computer data. These techniques reduce the scope of interest to a manageable size, allowing the user to concentrate on a reasonable amount of information at a time. As a result, the Constructability System allows the developer to encode knowledge efficiently and users to navigate through the sea of expertise interactively.

At the initial stages of this research, expert system software was considered as a potential implementation environment, but was not selected. First, expert system technology is new to construction companies, making its integration with other pieces of existing software more difficult and limiting its acceptability among potential users. Second, expert systems do not provide convenient access to external information and they experience significant performance degradation as the size of the accessible information becomes large.

Construction practitioners will not accept an assertion that a certain method is superior to another, without a sound rationale. An explanation facility, including the source and context from which the lesson was obtained, insures credibility and provides a reference for further investigation when necessary. An explanation facility has also proven indispensable when debugging or validating the system as it evolves from a prototype to a mature system.

After a rapid prototype was developed and demonstrated, users at a number of major contractors in Kuwait have found the system user friendly and realized the potential benefits. First, the system retrieval facility has been used by project managers, field engineers, superintendents and foremen engaged in field operation and in search of the most effective construction methods based on company experience. According to these users, the amount of rework has been minimized since mistakes can be avoided. The constructability feedback system earned credibility since the knowledge has been thoroughly refined and validated with the original experts and with a Total Quality Management Committee (TQM) that was established specifically for the purpose of reviewing and approving new lessons. The system is described as being flexible in retrieving information through the multi-classification option, and as fast in retrieval time. The system is used during the planning stage to alert engineers of potential problematic areas and the most effective ways of dealing with them. In this respect, the constructability feedback system is explored as a proactive planning tool in conjunction with a project CPM scheduling network. Also, the system is used as a reference library whenever an engineer, superintendent, or foreman is faced with a constructability problem.

The second important benefit reported by the users is the availability of a mechanism (i.e., Add/Delete/Modify a Lesson Option) to update the knowledge base and capture new and innovative construction methods as they become available. So, the process of expanding the knowledge base is partially automated, pending final review and approval by the TQM Committee. Lessons learned must be documented in a standardized format when they are fresh in mind. The task of submitting new lessons or commenting on existing lessons should not be arduous and time consuming, but needs to fit into everyday activities. An interactive capability via the use of menus is available within the system to submit new lessons. Once a lesson is proposed for inclusion into the system, technical review and classification of the lesson are conducted by the TQM Committee before release for widespread use. Many organizations have committees that address quality issues and would be a natural choice for this task. Figure 4 illustrates the operation of the system.

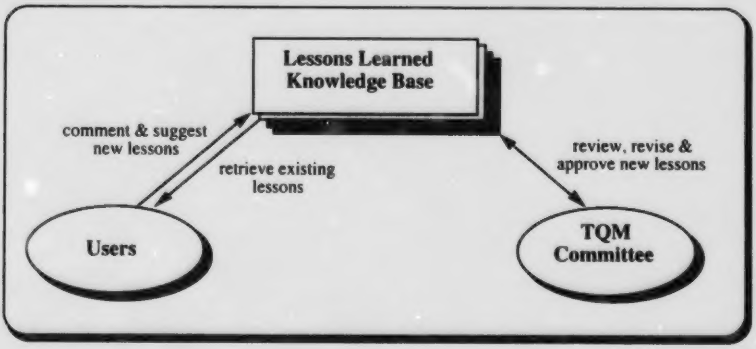


Fig. 4: The lessons learned system in operation

Since the knowledge base is quite limited in the development stage of a construction project, a major goal of the successful prototype is to generate enthusiastic support and a willingness to contribute personal experiences to system developers. As a recognition for contributors, the TQM Committee select the most fruitful lesson captured and identify it as "The Idea of the Week". The prototype is expanding with about six new lessons every month, mostly from superintendents. Such new lessons are now being submitted electronically. As the knowledge base grows and the number of participants increases, the TQM Committee must find the time and resources to review and approve lessons effectively.

7 Conclusions

Historically, the collection and dissemination of engineering/construction knowledge has proven to be difficult, but invaluable, when accomplished. This paper demonstrated the feasibility and potential benefits of making effective use of construction lessons learned. Key challenges to effectively utilizing feedback channels in the project life cycle were identified along with methods to meet these challenges.

The CII has called for improved documentation of lessons learned from the field. Although construction of a facility is typically viewed as a "one of a kind" operation, there is a considerable amount of repetition. Facades, bays and often entire floors are repeated. Lessons acquired in one project by a particular crew must be communicated to other crews on the same project as well as to other projects. As the CII advocates, a corporate "lessons-learned" database is a key element in any constructability program.

This paper described the design, implementation and operation of a prototype Constructability System using a database management system and hypermedia techniques. Such database environment combined with the use of a common classification format (i.e., CSI) permits integration with other computer-based construction systems and allows a more direct representation and modeling of real-world construction projects.

An interactive menu-driven capability has been incorporated in the Constructability System to ensure its continuous expansion and use by construction individuals within a contractor company. Such a dynamic, interactive system provides significant improvements in construction cost, schedule, quality and safety in planning and executing future construction work.

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240 USE OF AUTOMATIC KEYPHRASE GENERATION FOR CREATION OF A CONSTRUCTION THESAURUS

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Abstract

The paper describes development of a thesaurus in the roofing domain. This work is part of a larger effort to investigate the potential of thesauri as an aid in product modeling. Extractor, a software module that extracts keyphrases from documents, was used for collecting candidate thesaurus terms from Internet sources. The principal advantage of the Internet as a source of candidate terms is that it reflects colloquial language: -- the language that is actually used by building practitioners and that it covers the widest range of different 'user views' on the domain. The advantage of using Extractor or similar software is that it allows processing huge text *corpora* available on the Internet and it eliminates irrelevant terms. The methodology used was found to be highly useful, although it was not sufficient by itself for constructing a construction thesaurus, as considerable human intervention was required. Though limited time resources did not allow full exploitation of Extractor's capabilities, some possibilities for customization of the software and for partial automation of a thesaurus construction process are suggested.

Keywords: Thesaurus, Internet, automatic indexing software, thesaurus construction.

1 Introduction

A thesaurus is a set of terms that are used in a specific domain of knowledge, "formally organized so that a priori relationships between concepts are made explicit" (Aitchinson 1987). Originally intended for indexing and retrieving documents, thesauri have increasingly been seen as knowledge bases and used beyond the domain of librarianship (Kosovac 1998). The overall objective of this research direction is to investigate the potential of thesauri to assist the development of product models in the

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construction industry. It is believed by some (Vanier, 1994) that thesauri can assist to eliminate many semantic problems hindering the creation of robust product models for the industry. The main purpose of this research project is to explore the use of the Internet as a source of candidate thesaurus terms.

Extractor (Extractor 1998) is a machine-learning-based software module, developed by the Interactive Information Group of the National Research Council Canada, that scans an electronic document and extracts keyphrases best describing the document's "aboutness." This paper reports on the use of Extractor 2.0 as a support tool for collecting and selecting candidate terms for a thesaurus in the roofing domain, and more specifically, for low slope roofs.

In the process described, Extractor was used for a specific task and under given circumstances. Technological constraints — limited processing power, lack of programming resources for customizing Extractor and integrating it with other applications, as well as the unavailability of adequate software for advanced manipulation and analysis of Extractor's output, did not allow full exploitation of Extractor's capabilities. These constraints also precluded testing *corpora* large enough to provide statistically valid results. Therefore, the work described is of explorative nature and cannot be considered as a study that evaluates performance of Extractor 2.0. However, the patterns noticed in the analysis of the results can point to possible use of the software for related purposes and suggest possibilities for further research and/or development.

1.1 Description of the problem

The goal of the work described is to build a thesaurus based on Internet/intranet resources in the low slope roofing domain. It was also decided that it should follow the format of the *Canadian Thesaurus of Construction Science and Technology (TC/CS)*, a thorough, comprehensive, yet "dated" construction thesaurus (TC/CS 1978). The goal can be achieved as follows:

- selection of terms that can be extracted from the TC/CS to form a sectorial thesaurus,
- updating the sectorial thesaurus according to the development of the field and its terminology, and
- developing a micro-hierarchy of narrower concepts if required.

Alternatively, using the "bottom up" approach, the goal can be achieved by:

- collecting terms relevant to the field,
- selecting terms to be included in the thesaurus according to its intended purpose,
- checking the terms against the existing TC/CS thesaurus,
- organizing the terms into hierarchies following the TC/CS guidelines.

Standard sources for the initial collection of thesaurus terms usually include:

- terminological sources in standardized form; existing thesauri, dictionaries, glossaries, classification schedules, encyclopaedias, lexicons, journal indices, back-of-the-book indices, term lists, treatises on terminology of a subject field;

- literature scanning;
- question scanning;
- users', subject experts', and compilers' knowledge (Aitchinson 1987).

It must be noted that literature and question scanning play a crucial role for the usability of a thesaurus (literary and user warrant), while the other sources serve mostly for clarifying the meanings of terms, facilitating their arrangement into hierarchies and filling gaps.

1.2 Use of information technology in thesaurus construction

Along with their use for thesaurus-management, computers have been used for a long time for collecting thesaurus terms (Gilchrist 1971, Lancaster 1986, Aitchinson 1987). Their main use has been to derive terms from machine-readable sources and rank them by frequency of occurrence. Despite some successful efforts in automatic establishment of inter-term relationships, computers are still used only as support tools in this part of the process. Computers can assist human compilers by producing co-occurrence tables pointing to possible relations between terms, and clustering terms containing the same word or stem thereof.

2 Process

2.1 Approach to the problem

The TC/CS is a huge thesaurus (approximately 15,000 terms) covering a wide subject field. Searching it for all terms relevant to the subdomain would be an expert-labour-intensive process of following links throughout different hierarchies and numerous general terms, and deciding which terms are relevant and current. Possibilities for automating this task are minimal. Another problem is that the TC/CS is rather outdated, especially having in mind the significant changes in the field of low slope roofing that occurred in and around the 1980s, with the introduction of new materials and types of roofing systems.

On the other hand, the TC/CS has a thoroughly elaborated structure and well defined inter-term relationships that facilitates addition of new terms, given that their exact meaning is known. Furthermore, it is available in electronic form on the World Wide Web (http://www.nrc.ca/irc/thesaurus) thus allowing easy searching for known terms. For all these reasons using the "bottom up" approach suggested earlier seemed to be a logical solution to meet the goal of the work.

As the proposed thesaurus is intended for indexing Internet/intranet sources, the most useful source of terms would be *corpora* available on the Internet. The Extractor 2.0 documentation pointed to the suitability of the software for performing "literature scanning" of Internet sources as it:

- integrates HTML and e-mail filters and
- permits processing large *corpora* by extracting only relevant terms.

2.2 Preparatory tests

Since Version 2.0 of Extractor had been recently released (Version 3.3 is the current version), and since all known automatic literature scanning involved either title and abstract, or full-text scanning, the development of the methodology required some initial tests that would roughly examine available sources and Extractor's behaviour. The tests were done on documents retrieved by general search services such as Altavista (http://www.altavista.com) and the services listed below — and on documents from selected *web sites*. The documents were processed by Extractor 2.0 varying its *Beta* parameter; a performance measure based on the relationship between recall and precision. Here, precision means the percentage of the extracted keyphrases that are relevant, while recall represents the ratio of the number of relevant keyphrases extracted to the total number of relevant keyphrases in the document. The output of Extractor was intellectually analysed. The results and the limited resources necessitated the following modifications to the initially considered strategy:

> The query formulated with the intention to test harvesting *corpora* using automatically generated queries that combine synonyms of the top term (***summum genus***) and its immediate narrower terms;
>
> *("low-slope roof*" OR "flat roof*") AND ("built up" OR BUR OR "multi ply" OR "single ply")*
>
> did not provide optimum recall and precision within some search services As processing a sample large enough to compensate for the deficiencies was unrealistic, the query was modified into:
>
> *("flat roof*" OR "low slope") AND ("built up" OR BUR OR roofing OR membrane*)*
>
> that better reflected the language of relevant documents. Although the new query did not eliminate all the "noise", or did it ensure absolute recall, the retrieved sets of documents seemed acceptable for the purpose.

Extractor 2.0 proved to be significantly better suited for this purpose than the previous release. The initially considered strategy was to process documents with the lowest *Beta*, identify terms that should be added as stop phrases, cluster documents based on the rest of key-phrases, process them with *Beta*=2.0, and repeat the process until the desired level of specificity is achieved. However, the inability to frequently customize the software by adding new stop phrases and the labourious task of processing the same documents more than once made this strategy unfeasible. Using the new release with the highest *Beta* (i.e. maximized recall) and simply removing the most frequent keyphrases proved to provide satisfactory results. It must be noted that the Application Program Interface (API) for the Extractor Dynamically Linked Library (DLL) allows easy integration of the software with other applications. The limited time resources mentioned earlier, however, didn't permit the use of this feature.

It was observed that long documents that tended to be of high quality and that abound with very specific terms gave only too general terms in the Extractor output. Although keyphrases derived by Extractor reflect well the subject of the documents, they did not include specific terms that would be more useful for the purpose. The efforts to semi-automatically divide documents searching for heading tags did not prove feasible with most of the Web documents. It was, therefore, done only on a small number of scholarly papers that tended to be well-organized and had a better HTML structure.

2.3 Methodology

The goal of the work is to extract relevant terms from Internet documents, and not to evaluate Extractor 2.0. However, Extractor's performance has been continuously evaluated after each step, where not possible statistically then at least intellectually, in order to consider re-design of methodology or even give up the use of Extractor 2.0 if it would not produce the desired output.

Though most of the tasks had to be performed manually the methodology tried to follow computer logic in order to examine possibilities of automating the process or at least the use of clerical instead of expert labour ("artificial dumbness" approach).

2.3.1 Corpora

The following collections have been selected:

1. Documents retrieved by general search services
   The first (15) documents retrieved by advanced search with each of the five major general search services; AltaVista, Excite, HotBot, Infoseek, and Lycos; 75 documents altogether were used. Although most of the search services perform better with other search options, for consistency, the Boolean query or the option closest to it was used in each:
   ("flat roof" OR low-slope) AND (built-up OR BUR OR roofing OR membrane*)*
   The services were searched in alphabetical order, taking care to avoid duplicates. Where relevant documents from a certain site were grouped together, only the first one was used in order to avoid language of one author and frequent appearance of the same corporate names and trademarks.
2. IRC *Roofing Resources* (Roofing Resources 1998) collection
   This collection was included as it represents the core of the collection to be searched by the future thesaurus. Files bigger than 20 KB (arbitrarily established limit) were divided by headings to form 40 documents for the extraction of keyphrases.
3. Relevant documents retrieved at *FacilitiesNet* (FacilitiesNet 1998)
   The criterion for the inclusion of this site was its high content of documents relevant to the facilities-management aspect of flat roofs that is neglected in the majority of web documents, but important to the wider context of this work. Sixty-one relevant documents were retrieved and processed.
4. Collection of selected articles
   This collection was compiled by following links from various lists of relevant

sources but without aspirations to be comprehensive, exhaustive nor of highest quality. It has been included to allow comparison of the results with those achieved by automatic harvesting of sources using general search services.

Newsgroups were not processed separately because of difficulties in accessing "Dejanews" at the time and unavailability of adequate newsgroups archives. A small number of this type of documents was however included in AltaVista hits.

2.3.2 Procedure

Each document was processed by Extractor 2.0, with its *Beta* parameter set to 2.0, meaning the maximum recall of keyphrases. The extracted keyphrases were gathered in a list. The following information has been kept for each term:

- position in the Extractor list
- relevance factor number (provided by Extractor)
- document from which extracted

and for each document:

- collection ID
- size of the file.

After processing each set of documents the results were analyzed, compared with other sets, and the sets were finally integrated and processed together. The final set of keyphrases has been compared to the TC/CS, to the existing glossaries, and intellectually analyzed.

2.3.3 Criteria

Single- and multiple-word terms were not treated separately, as the list was not too big. Singular and plural forms of the same term were counted together but terms that may have different meanings when used in plural were specially marked [PL]. The terms were first searched in TC/CS for exact matches [=]. Qualifiers from the thesaurus were ignored in this step. Terms identified as general terms in the thesaurus were additionally marked [GT] and so were those that had further developed hierarchy of narrower terms [+].

After the identification of exact matches, single-word terms from the list were also searched for occurrence in phrases from the thesaurus [PH]. Extracted terms that are used as qualifiers in the thesaurus were also identified [Q]. The rest of the terms were searched for close matches [~], meaning those having the same stem. Intellectual analysis of the remaining terms identified phrases ill defined by Extractor [*], acronyms [A], proper names [N] and also the matches that have the same form but different meaning in the thesaurus [$].

3 Results

Terms with extremely high frequency of occurrence that should have been made stop-phrases were identified early in the process. These terms were the same for each set of documents and could have also been identified by processing the list with Extractor 2.0 with the lowest *Beta* (meaning minimum recall/maximum precision).

The results from the general search services were then compared with those from selected collections. There were no significant differences noted in terms of relevance of extracted keywords that would justify laborious and intellectually demanding task of searching, evaluating, and selecting sources. The quantity and diversity of documents that can be easily retrieved by general search services can compensate for the quality of sources. As the first 20 documents from the compiled collection did not bring new terms to the list, this collection was not further processed and it is not included in the final results. However, the documents have been saved for later comparison of scholarly and natural language terms and exploration of specific subareas.

The final list consists of 1054 terms (2423 occurrences) extracted from 176 documents. Almost half of the terms extracted were single words (49 %). They accounted for almost all of the top 4% most frequent terms with only two exceptions that would normally be included in stop-phrases. The usual practice of treating such terms separately was not followed as most of the terms were also identified as single word terms in the TC/CS.

A huge number of single occurrences of a term (78%) can be explained by the insufficient size of the sample. In order to extract relevant terms from this group, they were searched for component words and stems that could also be found in other terms. Terms found in this way were ranked higher in the list as more relevant. Rough scanning of the remaining single-occurrence terms found very few terms relevant to the field.

3.1 Comparison with the existing thesaurus

Checking the final list of terms against the TC/CS reveals a high relevance of the terms extracted by Extractor 2.0 to the field. Only terms that occurred more than once were actually searched in the thesaurus and numerically processed. Among 130 terms that appeared more than twice, 56% had exact matches in the thesaurus, 12% were found only in phrases, and 6% were marked as close matches. The matches were found in all semantic classes and in various hierarchies, showing a broad coverage of the domain. Among the remaining terms in the group, 3% were proper names, 2% acronyms, and 5% were marked as ill defined meaning that they could not stand alone as meaningful terms in the thesaurus (e.g. *install, installing, single, reinforcing, requiring, flat*). Terms that occurred twice had even more exact matches (63%) in the thesaurus but were less frequently found in phrases as they included more multi-word terms. Single-occurrence terms were not matched to the thesaurus at this point. The majority of mismatches, however, do not indicate irrelevance of the terms but more often the outdatedness of the TC/CS. The frequent occurrence of the term "membranes" for example, and the phrases containing it that are not found in TC/CS reflects changes in the field of low slope roofing and its terminology. The noise-making terms come from specific kinds of documents, mostly glossaries and book catalogues. Such documents can be easily excluded from the beginning by modifying the initial query.

Completeness of coverage is another problem that can be evaluated only after organizing terms into hierarchies (Petersen 1990). The relatively high coincidence of terms may also indicate a lack of more specific terms that would be required for developing a microthesaurus. Whether this is the case, can be established only later in the process.

3.2 Comparison with the glossary

The terms were also matched against relevant (i.e. low slope roofs related) terms extracted from a roofing glossary (Biegel 1989). The coincidence was much lower; only 31 % of the glossary terms were found in the Extractor's output. The unmatched terms were mostly very specific terms that are not a likely document topic (e.g. *alligatoring, back-nailing,* or *cutoff*).

4 Conclusions and recommendations

4.1 Observations on performance of Extractor 2.0

Extractor 2.0 appears to be a suitable tool for collecting thesaurus terms from the Internet. Although in the work described its use required extensive manual work, it is estimated to be more efficient than both manual and automatic full-text literature scanning. The principal advantage is that it allows scanning and handling a significantly bigger number of documents, thus providing better coverage of the field and its terminology. It can be rightfully expected that the use of the Extractor's API can make the task considerably easier and can multiply the benefits of this method.

The number of phrases marked as "ill defined" was 1% of all the terms extracted. Since the total automation of the thesaurus constructing process is not considered and since ill-defined phrases cannot cause serious consequences, this percentage can be considered ignorable. Therefore increasing recall even above *Beta*=2 in order to retrieve more specific terms would probably be safe. In most cases the lack of more specific terms in the Extractor output will not represent a deficiency; very specific terms are rarely included in a thesaurus and their presence might make one of the most important decisions in thesaurus constructing — where to stop, even more difficult. However, if constructing a microthesaurus, or if for any other reason more specific terms are needed, these terms may be obtained processing larger *corpora* or narrowing searches for Internet documents to be processed.

4.2 Observations on the Internet as a source of thesaurus terms

The Internet represents an extremely useful source of thesaurus terms. It provides huge *corpora* covering numerous aspects of a domain and different vocabularies — from the highly scholarly to the most informal. Internet documents reflect the language that is current, actually used in the field, and most likely to be used in queries. The results also showed that documents randomly harvested using general search services could provide equally valuable terms as controlled subject collections. The collected documents can be further analysed to complement the results of the described methodology.

4.3 Implications for the further work on the thesaurus

After establishing relationships between terms and organizing them into hierarchies of the existing thesaurus it can be expected that certain areas would need further development. Upon identification of such areas, gaps will first be filled with terms:

- derived by Extractor 2.0 from new sets of documents retrieved by more specific terms
- manually extracted from documents already retrieved and judged as relevant to the subfield according to keyphrases derived by Extractor 2.0.

Use of these two sources is prioritized for the reasons listed in subsection 4.2. However, these sources cannot ensure comprehensive coverage of the domain. Therefore, manual extraction of terms from alternative sources will probably be needed. Encyclopaedic and textbook type documents, roofing manuals, various kinds of term lists, and architectural details' labels are expected to best serve the purpose.

4.4 Possibilities for automating the process

Some of the tasks that could be fully or partly automated in applications used for similar purposes would include:

- automatic retrieval of relevant documents from the Internet and their processing with Extractor
- periodical processing of the list by Extractor for finding terms with significantly high occurrence and making them stop-phrases
- ranking terms by frequency of occurrence
- exclusion of terms that occur only once in large *corpora*
- automatic exclusion of geographic names
- grouping of terms containing same words or stems
- grouping of terms by co-occurrence in documents
- suggesting inter-term relationships by co-occurrence and syntax.

5 Final notes

The work described was carried out in February 1998. In the meantime a 336-terms pilot thesaurus has been developed (http://www.nrc.ca/irc/thesaurus/roofing). As these terms represent only a very small portion of the domain and of the terms collected in this process, final conclusions on the usefulness of the methodology cannot be drawn yet.

Full results of the study are available from the authors.

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241 AN INVESTIGATION INTO THE MAIN INFORMATION DIMENSIONS OF CORPORATE REAL ESTATE MANAGEMENT

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Abstract

The fragmentation of the construction and real estate sectors, and the information intensive character of their activities, makes it very difficult to select, store and transfer relevant information among its members. The volume and diversity of data in these sectors have been a hindrance for developing effective, integrated and standardised information systems for construction, building and real estate management. To overcome these problems at the level of strategic management of corporate real estate, a research was set to elicit the main information dimensions, or the main concerns, within the area. This research used as paradigms models that succeeded on defining and using the main dimensions of a particular subject matter, facilitating communications, decision-support and learning processes. Examples of these paradigms are the main factors of production in the theory of capital in economics, the balanced scorecard and the critical success factors in organisational management, the three dimensions in project management and Pena's (1987) main concerns for programming in architecture. The research consisted of a content analysis of seventy corporate real estate management (CREM) models used in industry and academia eliciting the main features (concepts, tools, techniques, methods) quoted on these models. Using classification techniques and supported by a literature review and expert interviews, these features were classified according to their nature, similarities and origin. The main dimensions resulting from this classification system provided the main information dimensions in CREM. These dimensions are financial, physical and human, each one divided in three classes, respectively. The financial dimension is divided in the classes rentability, business information and intelligence. The physical dimension is divided in the classes data, management and diagnosis. Finally, the human dimension is divided in the classes organisation, occupancy and customer. Examples of uses of the CREM framework are given.

Keywords: classification systems, corporate real estate management, metamodelling, facilities management, building management and maintenance, information dimensions, decision-support, content analysis of documents

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1 Introduction

The strategic management of organisational workplaces, as well as the land and buildings used for workspace, infrastructure and investment by public and private organisations, is receiving increased attention for various reasons. These reasons include: the internationalisation of the property market; the expansion of multinational organisations; new possibilities in terms of working patterns enabled by recent IT developments; the need to increase flexibility in the use of the factors of production; and finally, the need to align, clarify and synchronise strategy among organisational units to achieve a higher level of synergy.

A basic step in achieving strategy alignment, synergy and flexibility is a clear, simple and commonly known and agreed way to transmit information throughout the organisation. The research's objective was to elicit the main information dimensions in corporate real estate management (CREM) through a content analysis of CREM models and the use of classification techniques. The main result was the definition of the CREM information framework with three main information dimensions and their respective classes and content. These are the financial dimension, divided into rentability, business information and intelligence; the physical dimension, divided into management, diagnosis and data; and the human dimension, divided into organisation, occupancy and customers.

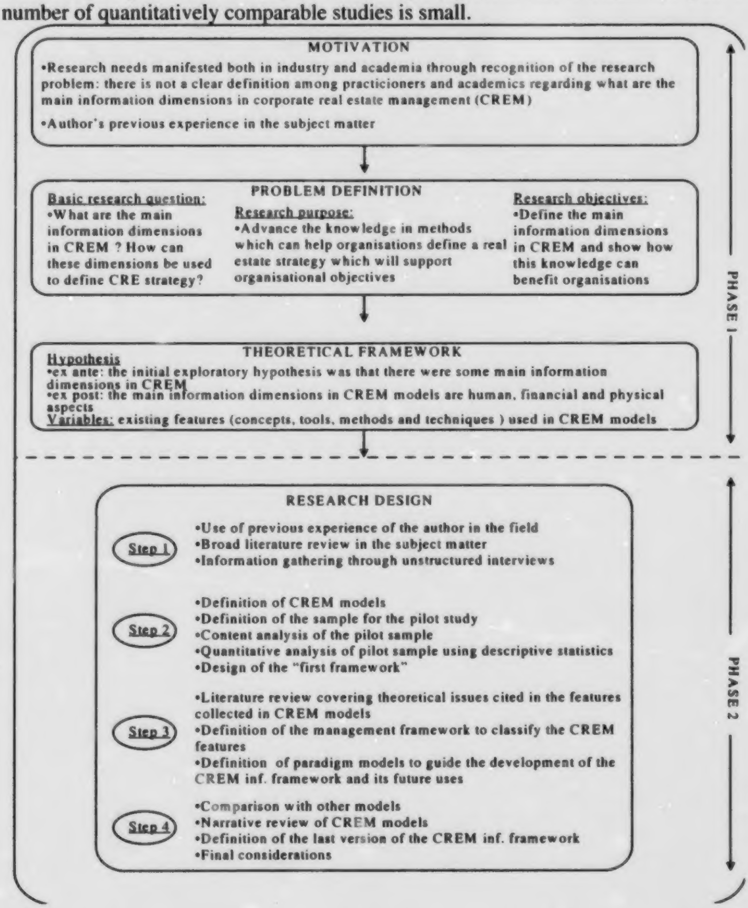
The research used widely accepted management tools such as the critical success factors, the balanced scorecard and others as paradigms of successful methods which achieved some of the objectives cited above. Common characteristics of these paradigms are simplicity, clarity, the elicitation of the main concerns or dimensions of the subject matter, and the ability to depict the whole picture and its parts concomitantly.

2 Research description

The research methods used resulted from a commitment to linking micro analyses of individual or group actions with a macro-structural analysis of the main dimensions of the subject matter in a methodological pluralist approach (Gill and Johnson 1991:125-131). The main research methods used were qualitative content analysis of documents and narrative review.

Content analysis is a qualitative or quantitative analysis of the content of written texts or other forms of communication, it aims to make inferences about individual or group values, sentiments, intentions, or ideologies as expressed in the content of communication (Sarantakos, 1993:211-17). Content analysis of documents was used to find out the CREM features (methods, tools, techniques and concepts) present in the models analysed. Some advantages of this method are: unobstrusiveness, accuracy, accessibility, low cost, spontaneity, high quality of information, possibility of re-testing, non-reactivity and retrospectivity. Some limitations of this method are: biased information, methodological problems such as coding, reliability, actuality (Weber, 1990; Krippendorff, 1980; Boulton and Hammersley, 1996).

Methods used to integrate findings across studies can be quantitative or qualitative, some authors reserve the name of meta-analysis for quantitative methods and narrative review for qualitative methods (Hunter and Smith, 1990). There are many methods of integrating findings across studies (Wolf, 1986; Hunter, Smith and Jackson, 1982). This research adopted a qualitative approach due to the lack of uniformity among studies and the relatively small number of studies with a similar structure and parameters which could be used in a quantitative analysis. As CREM is a recent discipline whose body of knowledge (BOK) is not a consensus yet, the number of quantitatively comparable studies is small.



- Research needs manifested both in industry and academia through recognition of the research problem: there is not a clear definition among practicioners and academics regarding what are the main information dimensions in corporate real estate management (CREM)
- Author's previous experience in the subject matter

Basic research question:
- What are the main information dimensions in CREM ? How can these dimensions be used to define CRE strategy?

Research purpose:
- Advance the knowledge in methods which can help organisations define a real estate strategy which will support organisational objectives

Research objectives:
- Define the main information dimensions in CREM and show how this knowledge can benefit organisations

Hypothesis
- ex ante: the initial exploratory hypothesis was that there were some main information dimensions in CREM
- ex post: the main information dimensions in CREM models are human, financial and physical aspects

Variables: existing features (concepts, tools, methods and techniques) used in CREM models

Step 1
- Use of previous experience of the author in the field
- Broad literature review in the subject matter
- Information gathering through unstructured interviews

Step 2
- Definition of CREM models
- Definition of the sample for the pilot study
- Content analysis of the pilot sample
- Quantitative analysis of pilot sample using descriptive statistics
- Design of the "first framework"

Step 3
- Literature review covering theoretical issues cited in the features collected in CREM models
- Definition of the management framework to classify the CREM features
- Definition of paradigm models to guide the development of the CREM inf. framework and its future uses

Step 4
- Comparison with other models
- Narrative review of CREM models
- Definition of the last version of the CREM inf. framework
- Final considerations

Fig. 1: Main phases of the research process

Figure 1 gives a summary of the two main phases and other intermediary stages followed during the research process.

These two methods were given priority because of the nature of the research. There are many case studies carried out on the subject matter and many surveys conducted among members of the industry, but not many studies integrating these findings. Therefore, there was a need to integrate existing studies in a framework using a common language, which was one of the objectives of this research.

The main data used in this research are the seventy CREM models analysed, due to the limited space available to quote all models and relevant CREM literature consulted in this research, this information can be found in Lopes (1995, 1996, 1997 and 1998).

3 Corporate real estate management (CREM) framework

The CREM framework aims to organise the main dimensions of the information used in CREM providing a perspective of the subject matter to students and managers and a suggestion towards the definition of a BOK for CREM. It also defines the main concerns of the discipline which can be used in conjunction with a decision-support procedure to align CREM and organisational strategy.

The strategy necessary to co-ordinate the activity of various agents working towards a common objective in different disciplines must consider the fundamental aspects within each one of these disciplines. The difficulty of the task can be assessed by listing the main disciplines involved in CREM: building management, concerned with building services and fabric; real estate management, concerned with property finance; facilities management, planning and programming, concerned with physical, psychological and behavioural needs of building users. To help in this task an information framework should consider the most important topics of all these disciplines. Some models used in other disciplines that follow this principle were chosen as paradigms for the construction of the information framework.

This kind of framework assumes special importance when considering recent workplace strategies. A popular workplace strategy nowadays consists of having an individual or a group focusing on a particular task, with the support of information networks, while being aware of their part in the organisation through a clear definition of organisational objectives (Brochner, 1990, 1993; Becker and Joroff, 1995). In this kind of environment, clear conceptual and institutional frameworks are necessary to locate individuals and their tasks within the final output of the organisation, i.e. within the final objectives, mission and vision of their own work group. Otherwise, in a very specialised and complex environment a skilled worker who knows only his specific task, and does not know its relationships to other organisational objectives, could hinder basic organisational objectives. In other words, this person could be destroying the very environment that provides for his or her survival.

The features elicited in the content analysis of CREM models were classified in groups according to their similarities, based mostly on the kind of information they used. These groups provided the basis for the main dimensions and classes of the information framework. The three main dimensions (financial, physical and human), considering stable traditional organisational functions, were subdivided into three classes each. Three other dimensions (technology, institutional issues and other information), considering unstable modern issues, were classified as a separate group of dimensions. The traditional academic and professional disciplines, which contain information used in CREM processes, were classified in another group. The objective of the framework is to define the main concerns within the information used in CREM.

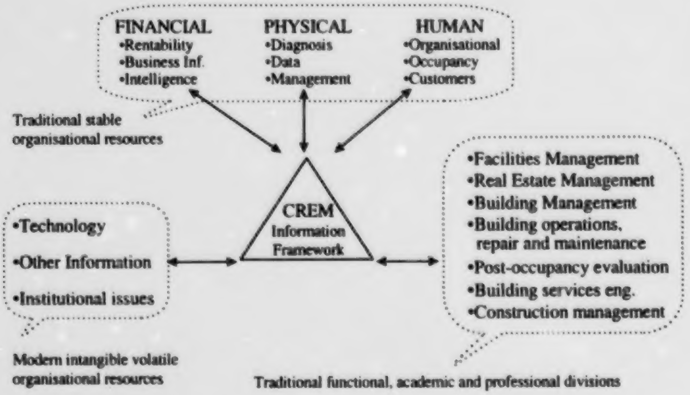


Fig. 2: CREM information framework

The content and features included in each dimension and its respective classes are described below.

- **Financial:** information on policies, costs, rentability, business strategy and market intelligence concerning CREM unit services (e.g. return on investment, market value, market research). Comparing to traditional organisational functions this dimension contains the information used by finance and other departments, such as, operations, marketing, research and development, and top management. It is divided into three classes: rentability, intelligence and business information.
  - **Rentability:** financial values and rates regarding costs, incomes, capital, depreciation and cost-benefit related to CREM.
  - **Business information:** information specific to the business system (or sector) on which the organisation operates (e.g. banking, retail, alimentation, manufacturing, hospitals, schools, hotels, airports, etc.) used to define organisational strategies and policies in real estate. Real estate industry-wide critical success factors are good examples of this kind of information.
  - **Intelligence:** information used in decision-support or strategy planning processes in CREM. As opposed to business information, this information can come from any sector rather than from the specific business sector in which the organisation operates. It usually comes from

traditional R&D or marketing departments or top management. It handles information regarding new tendencies, products, technologies or any other aspect which can provide competitive advantage to the organisation through new or improved CREM services.

- **Human:** information related to humans and their interactions with workspace, buildings and their surroundings (e.g. occupancy, customer satisfaction, productivity, present and future uses). Corresponds to information traditionally dealt with by human resources and marketing departments. It is divided into three classes: organisational, occupancy and customer information.
    - **Organisational:** information related to personnel policies, management and regulations within the organisation, such as, health and safety, recruitment, legal issues, contract, incentives, etc.
    - **Occupancy:** information related to the use of organisational premises such as churn, workplace strategies and management, workspace, personnel location and workplace's present and future uses and needs.
    - **Customer:** information related to client satisfaction considering both internal and external clients. Includes post-occupancy evaluation studies (POE) and market research.
- **Physical:** information related to managing and operating physical assets. It includes information about the materials that are used within the buildings and their surroundings (e.g. obsolescence, durability and sustainability of buildings and their component systems). Information usually dealt with by real estate, property, facilities, engineering and operations departments. It is divided into data, diagnosis and management.
    - **Data:** information from the asset register plus other data used for operations. The features used to store and manage this information are also considered in this class. This information includes local data for operational tasks and information on obsolescence, durability, sustainability and costs in use of physical assets.
    - **Diagnosis:** information and features used for assessment or decision-support concerning physical assets.
    - **Management:** information and features used in the procurement and management processes of physical assets.

As a consequence of the characteristics of physical assets the class "management" of the physical dimension had by far the greater number of features among the models analysed. To organise these features this class was subdivided in three subclasses. One subclass consists of the objects which are managed, this is in turn subdivided into premises, building services, and support services (can be considered in a Building Product Model). Another subclass groups policies used in the management of these objects which is subdivided in portfolio, cluster and premise. The third subclass groups features used to manage physical assets, which is subdivided into administrative tasks, building services and IT in building.

The generic dimensions 'technology', 'other information' and 'institutional issues' are considered separately because they have features which belong to any of the traditional dimensions as a consequence of their nature and high level of abstraction. Technology includes any new development which can be used anywhere in the organisation, in any of the traditional dimensions. Institutional issues include local legislation, regulations, contracts, conventions, norms of behaviour or any cultural aspect dependent on place or time. Other information includes any kind of information that would not fit into the three traditional dimensions, i.e. could not be easily classified into the CREM information framework in its current format—it is a buffer that accumulates unclassified data for future alterations of the framework.

4 Conclusions

The overall aim of this research was to find out what are the main information dimensions and their principal variables in the emerging discipline of corporate real estate management (CREM). Such a framework would facilitate strategic thinking at the top management level of corporate real estate. Being an emerging discipline in a new and broad subject area, within fragmented business sectors such as construction and real estate, CREM suffers from difficulties in the definition of its boundaries, priorities and integration of its diverse professional viewpoints.

The main conclusion of this research is that the information dimensions in CREM are financial, physical and human issues. These are represented in the CREM information framework together with their classes and other important organisational resources (see Figure 2).

Other important result of this research was the identification of paradigms for the framework, based on the qualities that caused their success (simplicity, clarity, robustness and the ability to allow the user to perceive the whole picture and its parts concomitantly). These paradigms can be divided into three groups. The first group is made up of decision-support procedures, the critical success factors (CSF) is the best example of this kind of paradigm. The second group is made of frameworks which describe the main concerns of a given subject matter. Examples of this kind are the main concerns in project management, the factors of production in the theory of capital and the main organisational levels in management theory. The third group of paradigms has both components, a decision-support procedure and the main concerns of the subject matter. Examples of this kind are the balanced scorecard and Pena's (1987) problem seeking technique for architecture planning.

These three groups of paradigms are not completely independent. The third group is made of frameworks which have the components of the other two groups. Therefore, a framework from one group can have an extra component added and become part of the third group. This would be the case when adding the CSF method with industry-wide CSFs for a particular business sector. Industry-wide CSFs which are based on the structure of a particular industry, although supporting particular organisational goals, are common to all organisations in that sector (Rockart, 1987).

The research process uncovered topics which could be developed by further research, some of these are: Definition of a resource library of CREM features implemented through object-oriented software—the framework and features elicited in this research can be used as a basis to develop a resource library of CREM features which can be implemented as software objects, in a similar way as the project developed by Scacchi and Mi (1994) to support the engineering of organisational processes throughout their life cycle; Utilisation of the framework in practical organisational settings for decision-support and strategy definition; Repetition of this research using digital data and appropriate software; Development of Behavioural Models for CREM based on principles of economics of information and uncertainty; Definition of what is the best decision support procedure to be used with the CREM information framework; Definition of industry wide CSFs for CREM, Definition of a CREM BOK based on the main concerns of CREM.

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242 EXPLORING THE APPLICATION OF CASE-BASED REASONING TO COMPUTER-ASSISTED CONSTRUCTION PLANNING

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Abstract

Computer-Assisted Construction Planning (CACP) is under development in support of Total Project Systems (TOPS). CACP, as a prototype application, employs a Case-Based Reasoning (CBR) tool, to address the requirements of information retrieval and subsequent reuse for preliminary project planning. The unique aspects of CACP include: 1) a design with respect to an integrated construction management system based on emerging industry information standards (i.e., Industry Alliance for Interoperability), 2) the consideration of quality, organizational, and procurement aspects of planning in addition to time, cost and scope, and 3) the application of CBR to facilitate the re-use of captured planning knowledge. CACP's data structure builds on past efforts of developing data standards within the AEC industry (e.g., ISO STEP and IAI IFCs) and contributes to current efforts with a focus in the construction management domain. With a solid data structure, CACP's planning approach can use organized specialization and aggregation constructs to promote efficient storage and retrieval mechanisms. The CBR tool is then used to guide the user to a past plan that best meets the current project requirements and presents this information for modification to meet all project requirements. The paper briefly describes the data structure and planning approach used and primarily focuses on the application of CBR to achieve a scenario where the re-application of past planning knowledge is possible.

Keywords: integrated construction management, construction planning, case-based reasoning

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1 Introduction

The "Total Project Systems" (TOPS) project includes the research, development, and implementation activities involving advanced construction management supporting software applications (Froese et al. 1997). The TOPS project is the focus of a research program within the Construction Engineering and Management Group at the University of British Columbia. Since the project's conception, TOPS have been succinctly described by three primary characteristics: comprehensive, integration, and flexibility. The ultimate goal of TOPS is to explore and demonstrate how integrated computer based tools can increase the overall efficiency of construction management operations.

TOPS accomplish this goal by supporting a broad range of functionality in support of traditional construction management tools such as estimating and scheduling as well as emerging management tools such as those that support construction methods selection or quality management activities. The key to efficiently supporting a broad and comprehensive range of functionality is to have a common source and structure of project information. Access and use of this integrated information must be available in an open-computing environment that is application independent.

A hurdle for the integrated systems described above and also for traditional stand alone information systems is the increasing requirements in the volume of information used. This increase is due to the increased functionality offered in addition to an increase in the number of users requiring access to the information, and the many different perspectives or views of the information required that vary in content and amount of detail represented.

To help overcome the information management challenges a solution based on the re-use of past project knowledge and information is proposed, along with an effective interface for handling this information. Both of these features draw from a shared database of information structured upon a standard industry representation. Computer-Assisted Construction Planning addresses the re-use component.

The approach adopted, therefore, is to structure the project information database on a data model that is consistent with on-going efforts within the Industry Alliance for Interoperability (IAI) and the International Organization for Standardization's (ISO) Standard for the Exchange of Product Data (STEP) working groups. The underlying assumption here is that, at some point, a common industry data standard will exist and be accepted and adopted industry wide. At this stage, the data model is static rather than dynamic (i.e., captures the current standard structures). However, it should be noted that the information modelling and development principles have been ensured, facilitating future changes to the data model to match changes to the data standards.

The user-interface employed is based on a commonly accepted 2-dimensional "tree and detail" scheme within a MDI (multi-document interface) approach. The implementation of 3-dimensional and more elaborate, and perhaps more efficient interfaces, are being pursued in a concurrent research effort at the University of New Brunswick (Rackley et al. 1998). The goal is to support the industry's acceptance of more efficient interfaces for integrated construction management systems. These may indeed be based on 3-dimensional approaches. For example, a 3-dimensional CAD representation for instances where the information is associated with a product centered data model and can be used for other management activities such as scheduling (so called 4-D CAD modelling).

The method by which information is represented in classification hierarchies is also an important ingredient to successfully managing project information. A standardized classification scheme is key to integration among applications and their overlapping functions. Efficient organization of information leads to effective use of the information.

2 Points of departure

The application of re-using past project knowledge and information builds upon previous research that is summarized under four distinct categories: industry standard data models, integrated construction management systems, classification schemes, and case-based reasoning.

2.1 Data representation

The methods of representing information and the structures required of data models for integrated construction management applications are well documented by Froese (1996). The most recent approaches in the field of construction management within the AEC (architectural engineering construction) domain are adopted to guide the structuring of the project database drawing from ISO (1992) and IAI (1996)

2.2 Integrated systems

Integrated construction management systems had their early start with the automation of scheduling and planning through the use of emerging AI techniques (e.g., Levitt et al. 1988; Waugh 1990). It was found that starting from so-called "first principles" and regenerating all the necessary information that is required for a single application, let alone integrated applications, was a challenging task. Work in this area then took a turn towards integrating the applications that are more widely accepted (scheduling and estimating), through the application of broader information technology approaches, with a higher level of information representation and use of templates or libraries of knowledge structures (e.g., Yamazaki 1995; Strumpf et al. 1996). To date, it is generally accepted that integrated construction management systems will be conceptually based on a central information source with which integrated applications and the industry participants will interact (O'Brien 1997).

2.3 Information classification

Interfaces and classification schemes have been around for many years and have evolved with the industry. In North America, MasterFormat (CSI 1995) is the best example of an indexing scheme that is used to support various organizing functions (e.g., technical requirement definition, and cost tracking and control). There are examples found in other countries as well, such as the European based Ci/SfB (Ray-Jones 1976) and its index tables. In light of the recognized importance of standard classification schemes to more sophisticated management systems within the industry, there has been a revamping of existing classification schemes. Evidence of this trend is found through the work of ISO sub-committee (ISO TR14177, 1994) and the British derivative of this work, the Unified Classification for the Construction Industry (UniClass 1998). In North America there is a new trend towards a product-centered scheme entitled UniFormat (CSI 1998). Although the UniFormat also serves the industry better in the definition of performance based work (the expected origin of its development), it also serves as an improved scheme for integrated management system approaches.

2.4 Case-based reasoning

The original hype of Case-Based Reasoning (CBR) began with Riesbeck and Schank's (1989) Inside Case-Based Reasoning; a text built on the flourish of Case-Based Reasoning research performed at Yale University in the late 80's. Today CBR is presented as a methodology for dealing with large quantities of information (Watson 1998) where various technologies (nearest neighbour, induction, fuzzy logic, SQL, etc.) are applied to the original algorithm.

As applied to planning, people do not construct plans from first principles, rather they try to find the best previous plan and adapt it to the current situation. A "case-based reasoner" solves new problems by adapting solutions that were used to solve previous problems with its elements of a case library and methods of storage, indexing, matching, and adaptation.

The basic algorithm that is applied is: 1. input the problem, 2. find the cases similar to the current problem (characterize the input problem, retrieve cases with matching features, pick the best match(es)), 3. adapt a previous solution to fit the current problem. In addition, concepts are required to support the ever-changing knowledge base that the CBR uses. To support these dynamic memory requirements, common information management concepts of inheritance, aggregation, specialization, and attribute definition are required.

3 CBR Applications to the A/E/C domain

Applications of CBR to engineering and construction include design (proportionally much higher), contracting, the application of building regulations, scheduling, and estimating. The following research is noted due to its similarity with the approach adopted for CACP, while bringing to light the issues involved with this application of CBR.

3.1 Design and design selection

Various systems that apply CBR to support design assistance and design automation are discussed in Maher and Gomez de Silva Garza (1997) along with the difficulties of their implementation. Voß (1994) describes a retrieval method for the selection of appropriate designs for building projects in the context of reusable parts rather than entire designs. Sycara et al. (1992) apply CBR to act as a designer's assistant in the design of mechanical devices. While Bilgic and Fox (1996) discuss case-based retrieval as used in engineering design within the context of an enterprise system. Finally, Flemming, U. et al. (1994) present CBR in support of early phases of building design. Although the area is not mature enough to lead to a generally accepted approach, there are many recurring themes noted that are equally applicable to the application of CBR to construction management.

In general, the two goals of re-using previously stored design information are to provide access to a large memory of past solutions, and act as an aid by providing designers with an initial solution available for editing by the system or user. Addressing these goals for construction planning is also the motivation for CACP. The first step is a solution to the representation of complex cases, where generalized knowledge and experience must be formalized. The common approach is to represent this information in an object-attribute schema while also maintaining categories for the various attributes (e.g., relation, function, behavior, and structure). Also, the reuse of solutions is applied across many phases of a projects design cycle (e.g., conceptual design to detailed design) and therefore retrieval must be available across a problem that is decomposed in a hierarchical structure.

Potential solutions must have a dynamic indexing mechanism because the retrieval process is iterative (i.e., the level of representation of the problem varies). Throughout the retrieval process the user is quite involved with the pruning process as a design develops and additional information is added. Therefore, using a hierarchical approach (relation attributes) allows access to potential sub-solutions.

A retrieval process is normally simplified by establishing the context of the problem through definition of a set of constraints. The context issue is dealt with up front by making it an explicit part of the query. Then, for each retrieval, a clustering of cases is performed based on the context. The method of retrieval and the means of indexing during retrieval are central to the process. First, the context of the information to be retrieved is established, then, the attribute-value pairs that will be used for retrieval are selected.

3.2 Other CBR applications

CBR has also been considered for application to other areas within the AEC industry. Yang and Robertson (1995) provide a framework for interpretation of building regulations, through abstraction hierarchies of legal rules from statutory regulations and previous relaxed cases. This example fits into the domain of CBR as applied to legal applications. Ng et al. (1998) apply a CBR tool and address case representation, indexing and retrieval, and adaptation for contractor pre-qualification by guiding the user through the processes of criteria formulation, screening and reviewing, final assessment based on financial and performance issues. Both examples show the potential of CBR as an effective aid to applications within the AEC industry.

4 Computer-assisted construction planning

CACP supports integrated systems by supplying the initial information required in a planning mode. Rankin et al. (1998) describes the functionality of CACP. The key components (features) of CACP are:

1 Data modeling - is based on an integrated data model with its roots in a general integrated project management data model.
2 Type and part information storage structures - allow efficient storage and retrieval, support multiple levels of detail during development through representation of general information (libraries), and specific information (current project).
3 CBR - employs artificial intelligence methodology for plan development, CBR presented as a methodology rather than a technology (the assisted component).
4 RAD (rapid application development) - tools are used for its development in consideration of integration and ease of implementation (low cost for a low cost technology industry) while also providing sufficient functionality.
5 Interfaces and classification - follow a growing trend in representing information that is hierarchical in nature by using an effective 2-D representation of information in a "tree and detail" combination.

4.1 The data model

The data model details the structure of the database used to store both general planning knowledge and current project planning information. This structure supports the common project management planning perspectives of time, cost, scope, and additionally supports performance and organization. The scope of the model for CACP is a subset of the Project Management data model described in Froese et al. (1997) and, as previously noted, is based upon on-going standard industry modeling efforts.

The data model was built using a customized database application built with Microsoft's Access and represented with Visio's graphical software. Therefore, the data model is static in its structure as opposed to the dynamic data model described in Gorlick and Froese (1999).

4.2 Construction planning

The "planning approach" is similar to that discussed in Froese and Rankin (1998). Briefly, the model supports the kernel information entities (product, process, resource and control) in "part" and "type" hierarchical relationships and fundamental relationships among these entities (e.g., process *applies to* product). A plan is developed by drawing from the general planning information, while considering the *context* of the current project (e.g., the specific project information available). For example, Fig. 1 illustrates selection of a process (build concrete column) to result in a given product (concrete column). By drawing from general planning information a process type is selected (e.g., build concrete column with conventional forms) which may contain sub-parts (e.g., set forms, place re-bar, pour concrete, strip forms).

Guiding this selection is the consideration of the *constraints* identified to this point in the project plan development (e.g., conditions that may limit specific column building operations). The mechanism for this retrieval process is the CBR component of CACP.

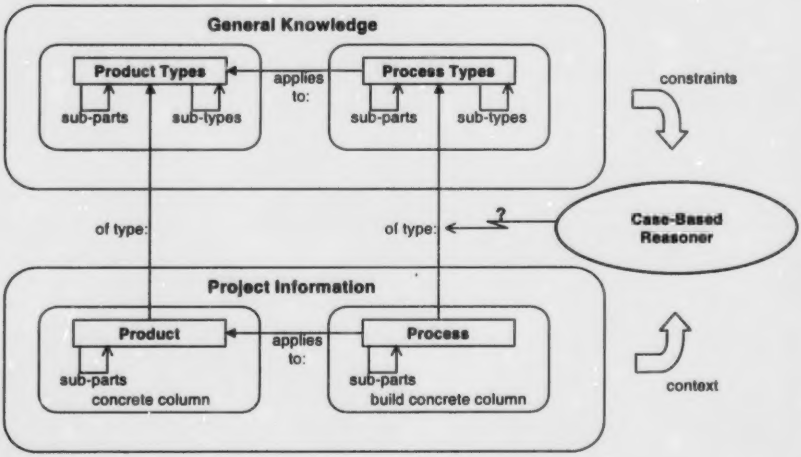

Fig. 1: CACP's planning approach

4.3 Case-based reasoning

The elements of CBR, as they relate to the implementation in CACP, are summarized in Table 1. As with the previously noted CBR applications to design, the primary issues surround the representation of cases, in consideration of the methods of indexing for effective retrieval and adaptation.

Representation of cases - the data model and its implementation is currently restricted to capturing simple attributes types (e.g., textual and numeric) without consideration for information of a graphical nature. The representation supports a hierarchical approach and follows sound information technology principles and the direction of standard industry data model efforts within the construction management domain.

Indexing - partitioning of the information stored is based on the kernel entities of the standard industry data model (i.e., products, processes, resources, controls). Clustering of information is achieved through use of a classification entity with a relationship to each kernel entity. The criteria for retrieving information will change as the project constraints are revealed and therefore the attributes selected for indexing must be dynamic and generated during each retrieval session.

Retrieval - cases are retrieved based on similarity matching of selected attribute fields while satisfying the constraints defined. Which attribute will be selected and priority of this selection is flexible to the user.

Adaptation - at this point adaptation will be left to the user, with minimal assistance provided by the system.

Table 1: Case-based reasoning implementation for CACP

CBR Option	CACP Solution	CACP Implementation
Representation of cases:		
Attribute-value pairs	attribute-value pairs	object model
Representation model	a model that supports part and type hierarchies	industry standard information model
Attribute types: text, numeric, images, & drawings	text and numeric, not images or drawings	restricted to MS Access relational database
Domain	restricted by representation model	building construction core model
Indexing:		
Partitioning	storage based on the kernel objects	library structure
Clustering	classification hierarchy or reasoner generated	classification entities
Dynamics	indexing generated by existing constraints (dynamic)	problem is defined by constraint storage
Retrieval:		
Context	guided by relationship attributes	object model
Nearest neighbour, induction	similarity matching on attribute fields	reasoner
Constraint satisfaction	will guide selection from system perspective	reasoner
System control	constraints	industry rules
User control	matching priority flexibility	assistance from system
Adaptation:		
Reformulation of problem descript.	none	tree interface (editing capabilities)
Assistance	guidance provided	tree interface
Automation	minimal	
Implementation:		
Reasoning	CBR shell	Haley Easy Reasoner
Storage	relational database	MS Access
Interface	graphical	MS Visual Basic

Implementation - the entire system is built in Microsoft's Visual Basic, making use of the Microsoft relational database engine with tables structured according to the model. The case-based reasoner is The Haley Enterprises "Easy Reasoner". The Easy Reasoner functionality is provided through a Visual Basic control and requires a minimal data conversion to flat dBase files during a reasoning session.

5 Conclusion

In support of TOPS we are searching for a tool to support the management and effective application of the large quantities of information required of integrated construction management systems. The application of CBR appears to hold promise in this regard.

CACP has been implemented as a very basic prototype with a minimal general information database. To this point work has focused on the development and implementation of the data model and an effective interface. The system will be populated with more examples as a means of further exploring the application of this methodology to construction management systems while contributing to further improvements in data model and interface developments.

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243 AN INNOVATIVE INFRASTRUCTURE FOR INTER-WORKING BETWEEN DISSIMILAR EDM SOLUTIONS

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Abstract

The paper gives an overview of the European Esprit Condor project (ESPRIT 23105). The project aims at providing a large range of industrial areas, including the Construction industry, with an innovative infrastructure for distributing information and achieving co-operative work between heterogeneous Electronic Document Management (EDM) legacy systems, while ensuring document consistency throughout ongoing projects. The paper, first, presents the proposed technical solution, and gives a comprehensive description of the Application Programming Interface supporting the proposed inter-working and semantic linking services. The paper also includes a brief description of the modelling infrastructure supporting the proposed Condor system. Finally, a demonstrator involving the AutoCAD application, along with the Electronic Document Management systems used within the project, is presented. The latter demonstrates the Condor semantic-linking services. The project is ongoing and supported by a user interest group, which involves representatives from a variety of non-construction industry companies all over Europe.

Keywords: Electronic Document Management, Object Modelling, Object Inter-working, Computer Integrated Construction.

1 Introduction

The construction industry has always been characterized by its conservative culture. As indicated in (Anumba 1998) several factors have contributed to this, including poor investment in construction IT, poor dissemination of research results, poor marketing, inadequate user-interfaces of systems, mismatch between construction IT innovations and industry need, and poor uptake of promising research prototypes by software developers. The latter was, in fact, used as a

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driving criteria in the setting up of the Condor consortium. The challenge was at the time to bring together construction IT researchers (University of Salford, KTH, CSTB), industry practitioners (Kvaerner construction, JMBygg, Derbi), and software developers (Cap Gemini, Carasoft), to overcome this conservative culture barrier.

The nature of the construction industry is such that teams are set up for specific projects and then are broken apart on their completion. Organisations and individuals participating in a team bring their own unique skills and resources, which may include proprietary applications and data. The software applications used may vary from one construction project to another, depending on the nature and complexity (in terms of project type, size, number of actors involved, etc.) of the project. These applications include software for managing electronic and paper-based documents.

The overall analysis of the current document management practices within the three construction companies involved in the project revealed the following limitations, inherent to their current system and work methods (Rezgui et al. 1998a):

- Every partner within the project must use the same EDM system on a project to be able to access and share documents.
- The document's semantics and internal structuring is not controlled by the EDM system. Documents are handled as black-boxes.
- The EDM system does not support document cross-referencing or semantic linking.
- Security is always an issue. It is not easy to implement as with printed documents. EDM systems require improved user authentication and document protection.
- The EDM system is not integrated with proprietary and commercial applications used within the company (e.g. CAD applications and word processors).
- Most end-users in the construction industry are not computer literate. EDM systems lacking user-friendliness, or used in a maladapted environment (e.g. network communication problems) discourage the user from using the EDM system.

The Condor consortium is aware of the fact that it is not possible to develop a unique document management solution for all the project partners, because of their investment in proprietary systems. In fact, a strong demand from the project end-users, and also from the non-construction industry members of the UK Condor user interest group, was identified. This is summarized through the following question: *is it possible to have, at any time, knowledge of the existence of a potentially useful piece of information used in a given project? Is there any easy mechanism to access transparently this information, update it (if it is inconsistent), delete it (if it is no longer needed), and cross-reference it to another piece of information, while keeping the entire (fragmented and distributed) project information base consistent?*

We must also add that the end-users wish to use their favourite document management system. The above question can be complemented with the following one from the technical team, that expresses, in a sense, the Condor vision: *is it possible to develop a Virtual Universal Browser that accesses information regardless of its form, format, and location, and that can easily be plugged into any legacy document management system?*

The idea of a virtual universal browser plug-in makes certainly sense. This browser will have to access a variety of heterogeneous information as described in Figure 1. This is one of the conditions that any organization will have to face in order to remain competitive. Information is power, and the effective use and access to information will empower any modern organization (including construction organizations) that strives to gain more market places and remain competitive.

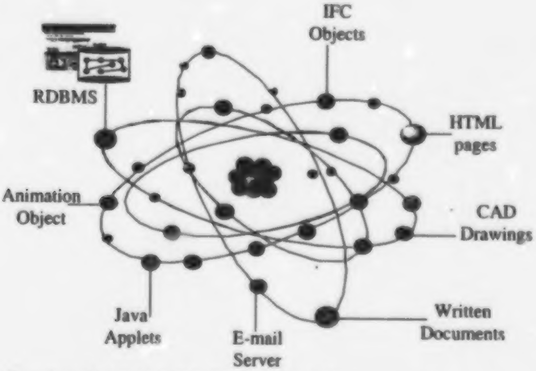


Fig.1: The Condor distributed information infrastructure

2 Proposed technical solution

A hybrid approach making use of the IDEF0 methodology and the Use Case approach (UML 1997) has been used to capture the requirements of the Condor system. It was found that both approaches were complementary and necessary for the understanding and specification of the proposed system. IDEF0 is used to define a high-level process activity model describing the document management practices taking place within the design and construction process. This is based on both the Infomate model (Bjork 1997), and the analysis and abstraction of the business processes and document management practices of the project end-users. A Use Case diagram, at a lower level, is proposed and detailed to describe the system in use. The proposed system architecture is presented in Figure 2. The major components of the architecture are described in detail in (Rezgui et al. 1998a), and include:

- the *CONDOR Integration Services* (implemented as a class library in the demonstrator);
- the *CONDOR API*, which defines the interface to the integration services. The main functions of the API are described below.

- the *Adaptors*, which provide the mapping between the CONDOR API and each of the document and object management systems to be integrated.

Before describing the Condor API, it is worth pointing out that the CONDOR references used by the API are globally unique. The format of these identifiers does not need to relate in any manner to the references used already by the differing EDM implementations. There will be functionality in each EDM adapter to map between CONDOR unique references and the EDM reference. An information object will have a globally unique (CONDOR) reference; parts of documents will have references also; this will be necessary for the semantic linking of documents. It is worth mentioning that the part references are assigned automatically as the document is written. The interface is provided between information providers and the CONDOR services (via the adapters and the API). The API includes the following functions:

- **Register() :** The purpose of the register() API method is to expose a document or other information element (object) to the CONDOR system so that it can be shared between EDM systems. The users can then examine the registered document in a manner that is familiar to them (i.e., as if the document were stored in their own EDM system). There are several approaches which can be taken in the CONDOR system regarding the registration of objects; one is to use a centralised registry (the approach taken during the prototyping phases); another is to use a wholly distributed system. If the distributed system is used then the CONDOR system will support both passive and active registration mechanisms.
- **Retrieve() :** Once a document or object has been exposed to the CONDOR system, it is necessary for other EDM systems to be able to use the document. This is enabled by the Retrieve method. It is worth mentioning that in order for an EDM system to retrieve a document or object exposed by the CONDOR system; it must know its corresponding Condor unique reference.
- **Store() :** In some cases it will be necessary for an end user to be able to store documents or objects themselves in an EDM system which is not local to them. In order to do this the Condor system needs to be informed of the location that the document/object is to be stored. As a result of the invocation of the Store method, a status is returned by the Condor system to the originating EDM system to notify the success or failure of the store method invocation. A successful invocation will cause a Condor reference to be returned which can be used at any time to manipulate the documents or objects exposed by the CONDOR system.
- **Search() :** In order for an end user to ascertain which documents or objects are exposed by the Condor system, some kind of searching mechanism is required. This method supplies the searching capability for the EDM systems.
- **Unregister() :** If a previously exposed document or object needs to be hidden, the unregister mechanism will make the document or object no longer exposed, and therefore unavailable via the CONDOR system. The document or object with the Condor reference given will be removed from the database of shared or exposed documents.
- **Retrieve_meta() :** If a remote EDM system requires more information regarding an information element or object, it can invoke this method in order

to get the required information. This method allows the user to retrieve the meta data associated with a document. This makes it possible to perform statistical analysis on the meta data without having to retrieve the complete document.

- **Store_meta() :** As it is possible to store a document or object in a remote EDM system, it should also be possible to store meta information about that document or object remotely. This method allows this to be done.
- **Lock() :** If it is necessary to stop access to a shared document for a temporary time, then the document or object can be marked as locked. This could happen if, for example, the document/object owner updates the document/object.
- **Confirm_lock() :** This method enables users or EDM systems (or even the Condor system itself) to discover if a document or object is locked or not.
- **Unlock() :** This method is used to remove the lock marker from a document or object. Once unlocked, the document can be accessed as a shared object.
- **AddCrossReference() :** This method creates cross references between information elements that are semantically related. An example illustrating the use of this method is given in section 4.

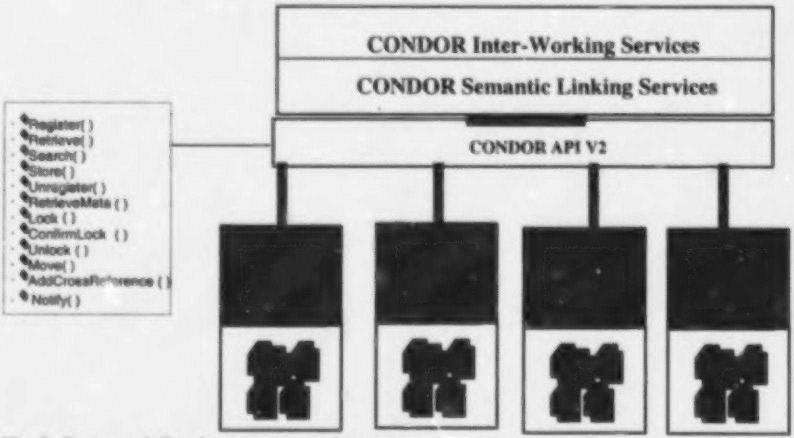


Fig.2: Proposed Condor system architecture

3 Modelling infrastructure

We have decided in Condor not to invest more in the Product modelling effort, but instead to concentrate on the development of an open object-based infrastructure that supports information sharing, cross-referencing, and inter-working between dissimilar legacy systems that are based on different data structures. We have, therefore, tried to make use as much as possible of existing work developed within companion projects funded by national (EPSRC) or European (including ESPRIT and JOULE) programs. A set of information models has been developed within the Condor project, as indicated in Figure 3.

The Unified Modelling Language methodology (UML 1997) was chosen to specify, visualize, and document the underlying artefacts of the proposed system.

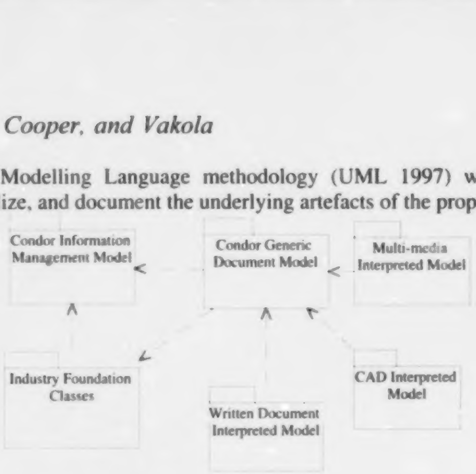

Condor Information Management Model
Condor Generic Document Model
Multi-media Interpreted Model
Industry Foundation Classes
Written Document Interpreted Model
CAD Interpreted Model

Fig.3: Condor modeling infrastructure

Figure 4 shows the basis for the handling of information versioning and right over Information Elements in the CIMM. The concept of Role is introduced, in the sense that all actors participate in a project by means of one or more roles. Thus it is the concept of a role rather than an actor that falls within the scope of the CIMM (Rezgui et al. 1998b). Through a role, an actor exercises authority over some parts of the project information, and each Authority is characterized by a number of responsibilities that relate to a particular object (Information Element). In order to discharge those responsibilities, the actor (through the role) needs to have certain rights to perform actions (or Operations) on the object in question.

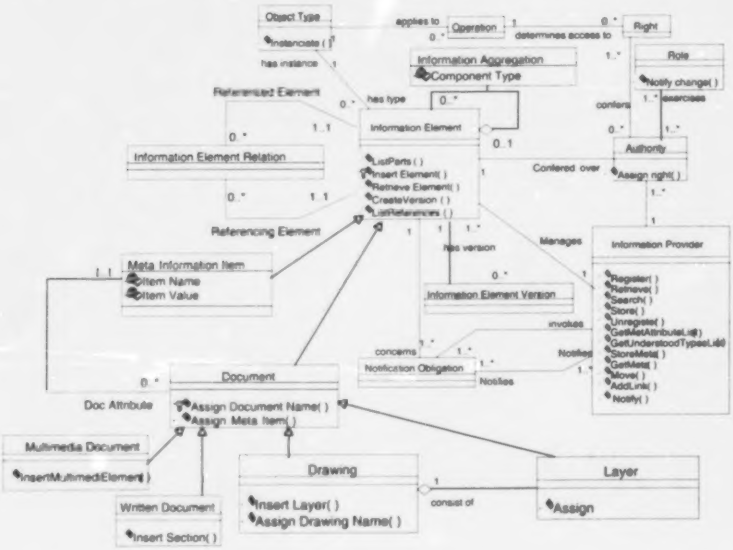


Fig.4: Overview of the Condor information management model

Figure 4 also describes the logical structuring and semantic linking between the various forms of information used in the industry. These include written documents, drawings and multi-media objects, and are all defined as being documents. An information element might reference, or be referenced, by any number of other information elements. The semantics of any association between information elements is defined within the Information Element Relation class, as indicated in Figure 4. An information element might also contain, or be part of, one or more information elements. For instance, a CAD layer might belong to more than one CAD drawing. The Information Aggregation class captures the semantic of this kind of aggregation between information elements. An information element is a versioned object that is specialized into a Document, and a Meta Information Item (that constitutes a set of attributes to the document). An information element might reference one or more Product Object(s) (this could represent an IAI / Industry Foundation Class).

4 Demonstration

The aim of the Condor prototype is to demonstrate the inter-working and semantic linking services of the Condor system. The demonstrator presented below made use of AutoCAD, along with the following legacy EDM systems:

- NOVA: it is a general purpose, Web based, EDM system developed by the Cap Gemini Group.
- SGT: it is a server of documents developed and used by Derbi. It is a conventional client-server application, running on both the Unix and NT platforms. The SGT NT version is used in the Condor project.
- Eureka!Filebase: it is a server of documents developed by Carasoft, and used by JM Byggnads AB. It bears similarities with the SGT EDM system.

Two strategies have been considered for implementing the inter-working services between the above mentioned proprietary EDM systems. In the first strategy, called *centralized registration*, any event (e.g. add, delete, modify) occurring on a Condor compliant EDM server is notified to a central database (*Registry*). The meta-data (e.g. title, abstract, author) describing the shared documents are looked up in this central database, while the documents themselves remain stored on the servers. The second strategy is called *distributed registration*. The central database is replaced by a *Brokerage* mechanism which has been implemented using CORBA (OMG 1996). Shared documents are looked up by broadcasting requests to the connected servers. The demonstration presented below makes use of the Centralized Registration Approach.

The AutoCAD package has been extended in order to support the main functionality of the Condor API. In the following scenario, the first step to using the AutoCAD extension is to start the Condor Browser. The latter is used to display the references of all the documents registered with the Condor system. The browser contacts the CONDOR-enabled EDM systems that it has been made aware of, and retrieves a list of documents. The user selects the document on which to work (in this instance, an AutoCAD drawing file) and opens the document from the browser's menu. The browser retrieves the document from the EDM system on which it is stored, and displays the drawing in AutoCAD (as indicated in Figure 5). Next, the CORBA connexion between the CONDOR Browser software and the AutoCAD library must be made by invoking the "Start ORB" command from the CONDOR menu item in AutoCAD (Figure 5).

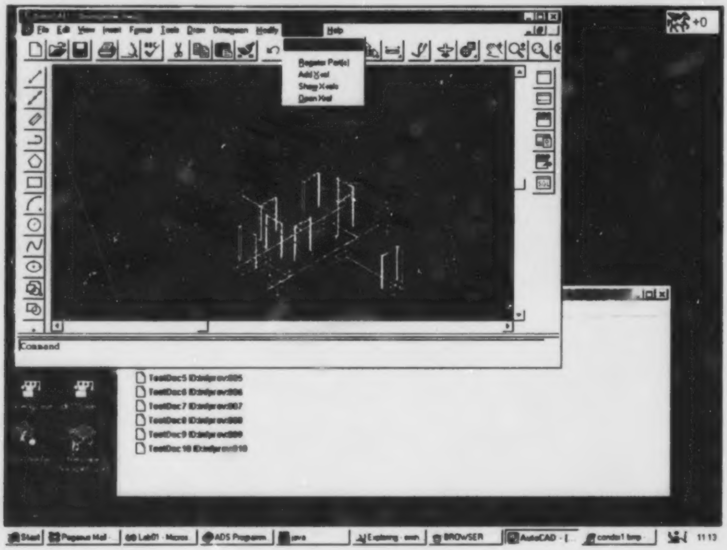
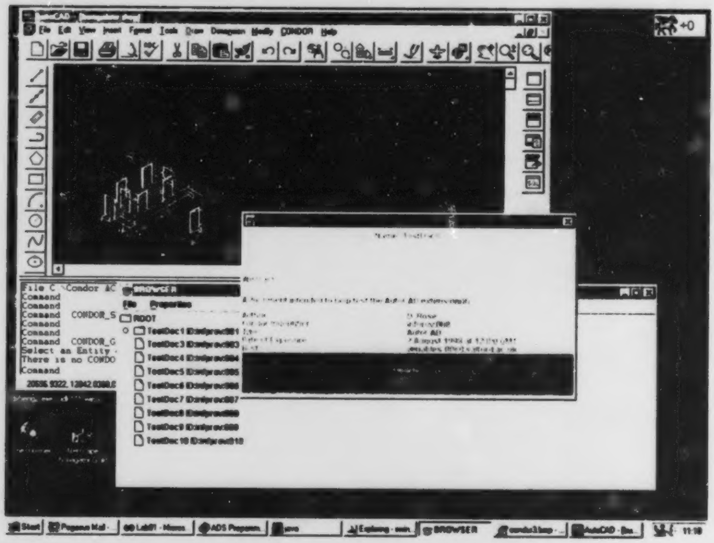


Fig.5: Condor compliant AutoCAD extension

Once the CORBA connexion has been made, it is possible to register parts of the drawing (for example, a door or a wall) with the CONDOR system. This method creates a unique Condor identifier for the drawing part which can then be cross referenced with other documents or document parts, which could be stored remotely. This is achieved by invoking the Register Part(s) command from the Condor menu of Figure 5. In order to add a cross-reference between a part of the AutoCAD drawing (e.g. door, window, or slab) and another document, the CONDOR Browser can be used to browse available documents which have been exposed through the CONDOR system. Once a document has been selected in the browser, the "Add Xref" menu command is chosen from within AutoCAD. This creates a reference between the chosen part from the AutoCAD drawing and the document which was selected in the browser.



```
File C \Condor AC
Command
Command
Command  CONDOR_S
Command
Command
Command  CONDOR_G
Select an Entity
There is no CONDO
Command
```

Fig.6: Cross Referencing a building part to a document

If existing cross references need to be checked, the "Show Xrefs" command from the AutoCAD menu can be used. This displays a dialogue box containing the cross referenced document identifiers. Lastly, a cross-referenced document can be opened on the machine running the AutoCAD and browser software. The requested document is retrieved by the browser from the EDM system, using the appropriate Condor API method invocation. The latter is displayed on the user's screen.

5 Conclusion

This paper presented the European Esprit Condor project. A description of the technical solution along with its components (including the Condor API) is given. An overview of the modelling infrastructure supporting the system is also given. The models and API methods are still being refined in the light of experience from implementation work. Some functionality of the Condor prototype demonstrating the semantic linking and cross-referencing services (using the Corba technology) are illustrated in the paper. The consortium is now finalizing the last version of the prototype (V3) that will hopefully validate the overall approach taken in the project. The main problem that the consortium is now trying to overcome is the change of culture. The organisation and processes of construction projects must change in order to deliver the expected benefits. Therefore, the construction project lifecycle, from concept development to demolition and recycling, need to be examined and re-engineered. The Condor project includes an important BPR component. The Business Process Re-engineering research is still ongoing and aims at defining the appropriate process redesign strategy, within each company involved in the project, to implement effectively the proposed solution.

6 Acknowledgements

The authors would like to thank Bo-Christer Bjork (from University of KTH), Duncan Rose (from University of Salford), Jean-Yves Magadur (from Cap Gemini Innovation), and Marc Bourdeau (from CSTB) for their contribution to the research. The authors would also like to thank all the other members of the Condor consortium (JM Bygg, Kvaerner Construction and Derbi) and wish to acknowledge the financial support of the European Community under the ESPRIT program (ESPRIT 23105).

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244 SL/AM-IT: A CD-ROM-BASED, INTERACTIVE BIBLIOGRAPHY ON SERVICE LIFE AND DURABILITY

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Abstract

This paper describes a technology transfer technique to handle large *corpora* of technical information. The paper describes and illustrates a sophisticated Information Technology tool to interactively browse over 1500 abstracts and full text documents in the domain of service life and asset management. The first goal of the project is to provide full access to this compendium of information in the topic domain. The second goal of the project is to illustrate a methodology for data storage, data retrieval and technology transfer for other technology domains. The product described in this paper is a compact disk-read only memory (CD-ROM)-based, interactive bibliography on service life prediction, durability and asset management. There are two innovative features of this compendium: (1) a keyphrase index, that was created automatically using sophisticated indexing tools, and (2) an intuitive, interactive interface to large volumes of technical information. The paper describes the problems of accessing the existing large volumes of data and information related to service life prediction, durability and asset management, outlines sophisticated IT tools currently available for indexing and searching large *corpora* of technical information, details the interface and background data structure of the SL/AM-IT (Service Life/Asset Management-Information Technology) methodology and product, and discusses advantages of such techniques in the domain of service life and asset management and other similar technical domains.

Keywords: Bibliography, service life, durability, CD-ROM, Compact Disk, keyphrases, interactive, Internet.

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1 Introduction

This paper describes a technology transfer technique to handle large *corpora* of technical information. The paper describes and illustrates a sophisticated Information Technology (IT) tool to interactively browse over 1500 abstracts and full text documents in the domain of service life and asset management.

The first goal of the project is to provide full access to this compendium of information in the topic domain. The second goal of the project is to illustrate a methodology for data storage, data retrieval and technology transfer for other domains.

The product described in this paper is a compact disk-read only memory (CD-ROM)-based, interactive bibliography on service life prediction, durability and asset management. There are two innovative features of this compendium: (1) a keyphrase index, that was created automatically using sophisticated indexing tools, and (2) an intuitive, interactive interface to large volumes of technical information. The paper describes the problems of accessing the existing large volumes of data and information related to service life prediction and asset management, outlines sophisticated IT tools currently available for indexing and searching large *corpora* of technical information, details the interface and background data structure of the SL/AM-IT (Service Life/Asset Management-Information Technology) methodology and product, and discusses advantages of such techniques in the domain of service life and asset management and other similar technical domains.

2 Problem description

2.1 Background information

There has been considerable research work accumulated in the combined fields of service life and asset management; however, much of this information is spread over a wide selection of documents, sources and countries. In the past 40 years, there has been considerable effort by researchers to create this compendium of knowledge; but there is no one central location for the accumulation of this valuable storehouse of information. Journals, conference series, monographs, on-line databases, Internet World Wide Web (WWW) sites and some other CD-ROM are available; however, for many organizations, these references are difficult to locate and many can be expensive to acquire, if they can be located in the first place.

The current search tools for locating this information are not standardized, and many are extremely sophisticated, requiring considerable training to master and normally expertise in library sciences. In addition, there are a number of administrative and legal issues involved in making such information available, including availability of the source documents and copyright laws.

Clearly, in a mature research domain such as service life prediction, durability and asset management there is a considerable *corpora* of technical information, and there are knowledgeable users who require immediate access to this *corpora*, and additionally, many of the copyright owners of the information are public bodies who promote progressive technology transfer. All that remains is to provide a mechanism to publish this *corpus*, so it is easily accessible to a wide audience of users.

2.2 Technology transfer agenda for CIB and RILEM

The work plan for CIB W080/RILEM 175-SLM (Service life methodologies) follows closely the developments made in the previous joint CIB/RILEM working group on "Prediction of service life of building materials and components" (CIB W080 1999; Jernberg *et al.* 1997). It is based on the elaboration of key areas of knowledge in the service life domain that together provides practitioners with the necessary tools to guide their decisions. The five areas include:

1. Information Technologies in Construction: an Integration Tool in service life prediction
2. Service Life and Durability
3. Selection of Service Life Prediction Methods
4. Understanding Factors Causing Degradation
5. Characterisation of Degradation of Building Materials and Components.

Since 1982, there have been three consecutive joint CIBW80/RILEM Committees, including 71-PSL, 100-TSL and 140-TSL. In this time, members of numerous countries participating in the joint activities have done considerable work. Indeed, this group has been responsible for a series of useful working documents and related literature published by CIB and RILEM and as well, has co-ordinated the efforts required to bring about seven international symposia related to durability and service life issues. The number of significant contributions collectively presented in these conference proceedings provide a substantial depth of knowledge to the field. Full exploitation of this vast body of knowledge for the benefit of manufacturers of building materials and components, designers, specifiers, constructors, as well as asset and property managers, requires the development of suitable guides and related information for use by these various practitioners.

It is the aim of the current CIB W80 Working Commission (WC), working jointly with RILEM 175-SLM, to help develop the necessary guides, methods and techniques that will enable practitioners in selecting the appropriate tools to predict service life. In fact, many of the future contributions of the WC may very well find a place within international standards, as the current working commission actively participates in providing technical expertise to the relevant ISO Working Group developing a standard on Design Life of Buildings. To achieve this aim, it is proposed that existing service life techniques be further developed in the context of emerging information technologies. Hence, the focus of the WC is the integration of existing prediction and service life techniques, tools and methods, using information technologies being developed for the construction industry. Furthermore, stochastic and reliability methods, typically used in the aerospace and automotive industries, will be reviewed as potential means of addressing particular aspects of service life prediction (SLP).

2.3 Existing *corpora* of information

CIB W80/RILEM 175 SLM, and the proceeding WC's have had an active program in technology transfer for a number of decades. For the past 25 years, many organizations have put their names behind a series of triennial conferences entitled the *Durability of Building Materials and Components* (DBMC), including the National Research Council Canada (Sereda and Litvan 1978), the National Institute of Standards and Technology (Frohnsdorff and Horner 1981) VTT (Sneck and Kaarresalo 1984), National University of Singapore (Lee 1987), Building Research Establishment (Baker *et al.* 1990), Building Research Institute (Nagataki *et al.* 1993), and the Royal Institute of Technology (Sjöström 1996). In addition, a number of journals related to this topic have come and gone, including *Durability of Building Materials* (Elsevier 1987). Other congress proceedings related to this topic domain have also been published, including CIB's *Building Technology, Design and Production* (Sjöström *et al.* 1983) and RILEM's *Durability of Construction Materials* (Maso 1987). These publications form the *corpora* of information for the SL/AM-IT CD-ROM.

2.4 Copyright issues

Fortunately, the copyright to the described *corpora* of information is held by a number of organizations that are interested in making their knowledge more widely available. The authors made contact to secure copyright to the abstracts for the SL/AM-IT CD-ROM either with the proceedings' publishers or host organizations. In the case of the previous seven DBMC conferences, the host organizations and the proceeding publishers were only too happy to see their information resurface in another form, and made their abstracts available. In the case of 8th DBMC, the National Research Council of Canada (NRCC) holds the copyright, and as such, made access to the full text of the documents a possibility. In the future, it is hoped that subsequent DBMC conference organizers or publishers of related journals will make their articles a part of future releases of SL/AM-IT.

2.5 Technology transfer

There are a number of solutions available to address this identified need for rapid access to *corpora* of technical information related to the domain of service life and asset management; some of these are IT-based. New IT tools and techniques now make it possible to create sophisticated applications that would have been extremely expensive to create even a short time ago. The Internet protocol that is in common use on the World Wide Web (WWW) is such a tool (Vanier and Turk 1994). The rapid evolution and universal acceptance of the Internet and the HyperText Markup Language (HTML), provide opportunities for capturing, storing and disseminating information of a technical nature, and in particular would be particularly useful when dealing with the *corpora* of knowledge on service life and asset management. The current implementation of SL/AM-IT is a CD-ROM; however, owing to the use of HTML in the project, there are plans in place to make this *corpora* available on the Internet.

3 Materials and methods

The two goals of the project identified earlier were: (1) to provide full access to specific corpora of knowledge, and (2) to illustrate the methodology for other applications and domains. Two innovative features of SL/AM-IT are: (1) a keyphrase index, that was created automatically using sophisticated indexing tools, and (2) an intuitive, interactive interface to large volumes of technical information. In summary, the system had to be comprehensive, quick and intuitive (user-friendly) for the users, and it had to be easy-to-construct for the developers.

3.1 Process description

Figure 1 outlines the stages followed to bring the data together for the CD-ROM. Starting from the left in Figure 1, the hardcopy documents were scanned using "off-the-shelf" technology, Optical Character Read (OCR'd) using commercial software, and proof-read by (human) editors; thus creating electronic copies of the abstracts and associated information. The two lead authors, in their role as organizers of the 8DBMC, had access to the electronic files for all the conference contributions, so this formed part of the *corpora* of information for the CD-ROM.

These electronic files were processed, as illustrated in the centre of Figure 1, to create the electronic indexes required for the database searching.

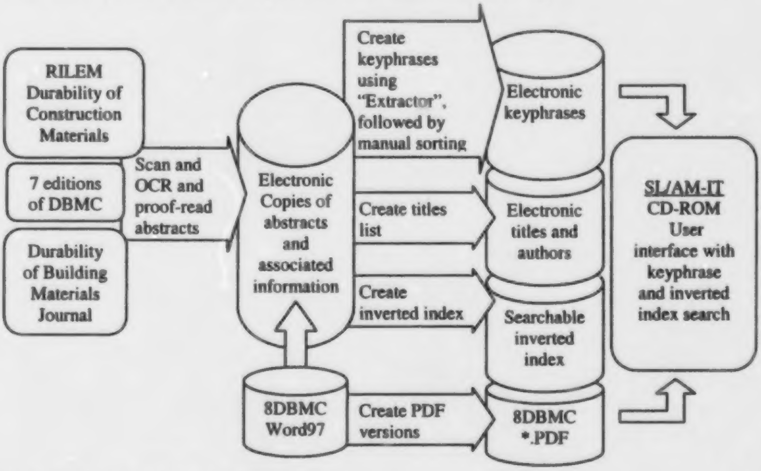

RILEM Durability of Construction Materials
7 editions of DBMC
Durability of Building Materials Journal
Scan and OCR and proof-read abstracts
Electronic Copies of abstracts and associated information
8DBMC Word97
Create keyphrases using "Extractor", followed by manual sorting
Create titles list
Create inverted index
Create PDF versions
Electronic keyphrases
Electronic titles and authors
Searchable inverted index
8DBMC *.PDF
SL/AM-IT CD-ROM User interface with keyphrase and inverted index search

Fig. 1: Process and implementation

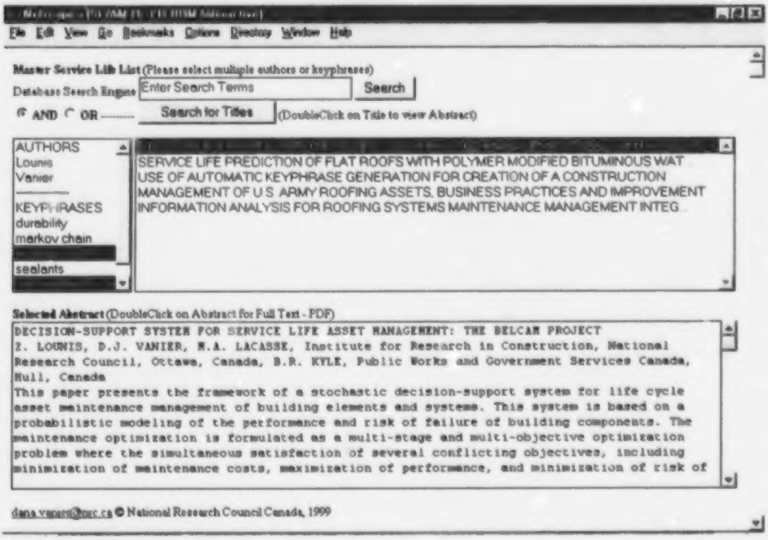
3.1.1 Extractor software

The Institute for Information Technology of the NRCC has developed a software product that uses the full text version of documents to create keyphrases (Extractor 1999). This program was used successfully in a related project (Kosovac and Vanier 1999), and the authors saw many opportunities for such a technology in the storing and dissemination of technical information. The general theory behind the "Extractor" methodology is that automated tools can systematically and objectively create keyphrases from full text documents. One of the advantages of using this automatic generation of keyphrases, such as the "Extractor" methodology, is the objectivity in the selection of keyphrases; normally, authors always have some form of bias in their selection of keyphrases. Computer generation of terms is also precise, repeatable, fast and simple (Turney 1997). "Extractor" has been successfully benchmarked against a number of other "indexing" software (Turney 1997).

To create the desired keyphrases for indexing and searching for SL/AM-IT, the individual abstracts and full text documents from the *corpora* were individually indexed using "Extractor"; this produced six keyphrases per document. This list of keyphrases was combined with the keyphrases supplied by the authors, and a domain expert purged the resulting list for duplicates and similar keyphrases. The resulting short list formed the "pick list" of keyphrases for the *corpora* searching.

3.1.2 Title and author lists

Title and author lists were also created for searching; thus allowing the user to specifically identify authors from the "Master Service Life List", shown in Figure 2.



Master Service Life List (Please select multiple authors or keyphrases)

Database Search Engine: Enter Search Terms

● AND ○ OR

(DoubleClick on Title to view Abstract)

AUTHORS
Lounis
Vanier

KEYPHRASES
durability
markov chain
sealants

SERVICE LIFE PREDICTION OF FLAT ROOFS WITH POLYMER MODIFIED BITUMINOUS WAT
USE OF AUTOMATIC KEYPHRASE GENERATION FOR CREATION OF A CONSTRUCTION
MANAGEMENT OF U.S. ARMY ROOFING ASSETS. BUSINESS PRACTICES AND IMPROVEMENT
INFORMATION ANALYSIS FOR ROOFING SYSTEMS MAINTENANCE MANAGEMENT INTEG

Selected Abstract (DoubleClick on Abstract for Full Text - PDF)

DECISION-SUPPORT SYSTEM FOR SERVICE LIFE ASSET MANAGEMENT: THE BELCAM PROJECT
Z. LOUNIS, D.J. VANIER, M.A. LACASSE, Institute for Research in Construction, National Research Council, Ottawa, Canada, B.R. KYLE, Public Works and Government Services Canada, Hull, Canada
This paper presents the framework of a stochastic decision-support system for life cycle asset maintenance management of building elements and systems. This system is based on a probabilistic modeling of the performance and risk of failure of building components. The maintenance optimization is formulated as a multi-stage and multi-objective optimization problem where the simultaneous satisfaction of several conflicting objectives, including minimization of maintenance costs, maximization of performance, and minimization of risk of

dana.vanier@nrc.ca © National Research Council Canada, 1999

Fig. 2: CD-ROM: Hypertext user interface

3.1.3 Inverted index

A standard inverted index of the text documents forming the *corpora* of knowledge was created for rapid searching. An inverted index creates of table of terms used in the *corpora* along side their exact location in the documents. The user simply enters the desired term for searching and the contents of the *corpora* are quickly scanned. This type of "search engine" is a standard feature of the Internet.

3.1.4 Portable Document Format (PDF) files

As illustrated in Figure 1, the Portable Document Format (PDF) files for the 8DBMC contributions form part of the *corpora* of SL/AM-IT. The text versions of these documents were also indexed using "Extractor".

3.2 SL/AM-IT interface

The graphical user interface was designed to provide a number of access points to the database, including the keyphrase information provided by the author, the keyphrases provided by Extractor, as well as the inverted index and the full text of the PDF files. Features of the user interface are described in the following sections.

3.3 User interface design

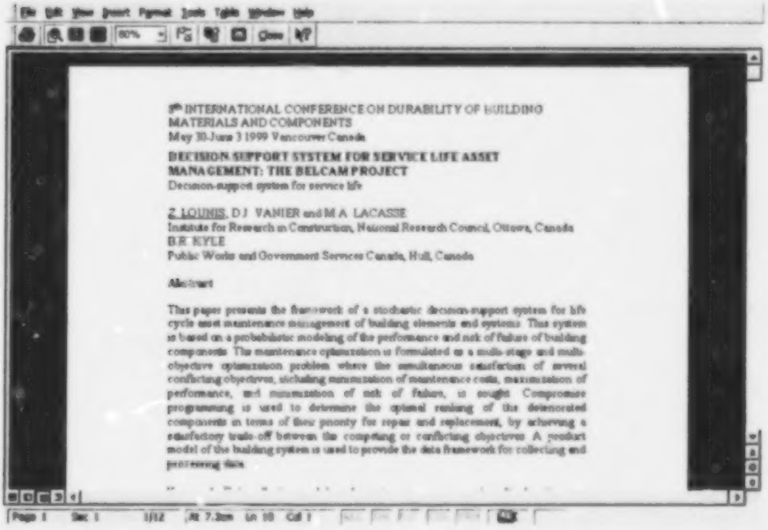
Figure 2 illustrates the search input screen for SLAM-IT. This is a typical WWW interface using standard HTML. The interface can be used with any number of Internet browsers, allowing complete portability of the SL/AM-IT data and interface. The search options are found at the top of the screen in Figure 2, where the user can use the inverted index to select specific "free form" terms or the keyphrase options.

The middle portion of Figure 2 shows the interface where the user can select a number of keyphrases and/or author names. In the example shown, the keyphrases "roofing" and "service life" were selected. The user can request either "AND' or "OR" Boolean operations to be performed; the results of the "AND" operation are shown in the centre right of Figure 2. Five articles form the results of searching on both those keyphrases. To view the abstract for the first listing entitled "Decision-Support System for Service Life Asset Management", the user double-clicks on that output line and the abstract appears at the bottom of Figure 2. The three input fields described above are all scrollable; allowing the user to browse over the data any number of times until a suitable article is located. If the full text version of the document of interest is available on the CD-ROM, then the user clicks on the abstract to view the PDF file for that article, as shown in Figure 3.

3.4 System design

Figure 4 provides an illustration of the system design for the SL/AM-IT CD-ROM. The "Author/keyphrase" lists, shown at the left of Figure 4, have many-to-many relationships to the "Title Lists". That is, there can be many authors and many keyphrases for each paper, as well as, each author and each keyphrase can appear on a number of papers.

In the centre of Figure 4, each "Title List" entry points to one abstract citation (including the listing of the name of the publication, article title, list of authors, author affiliations, and author-created keyphrases). There can be PDF full text documents for some of the abstracts in the "Abstract List", as shown on the right of Figure 4. This software design permits a simple and easy-to-manage mechanism to locate files using standard HTML protocols.


File Edit View Insert Format Tools Table Window Help
80%
Close
Page 1 Sec 1 1/12 At 7.2cm Ln 10 Col 1

8th INTERNATIONAL CONFERENCE ON DURABILITY OF BUILDING MATERIALS AND COMPONENTS
May 30-June 3 1999 Vancouver Canada

DECISION SUPPORT SYSTEM FOR SERVICE LIFE ASSET MANAGEMENT: THE BELCAM PROJECT
Decision-support system for service life

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Abstract

This paper presents the framework of a stochastic decision-support system for life cycle asset maintenance management of building elements and systems. This system is based on a probabilistic modeling of the performance and risk of failure of building components. The maintenance optimization is formulated as a multi-stage and multi-objective optimization problem where the simultaneous satisfaction of several conflicting objectives, including minimization of maintenance costs, maximization of performance, and minimization of risk of failure, is sought. Compromise programming is used to determine the optimal ranking of the deteriorated components in terms of their priority for repair and replacement, by achieving a satisfactory trade-off between the competing or conflicting objectives. A product model of the building system is used to provide the data framework for collecting and processing data.

Fig. 3: Full-text, printable and searchable version of the document

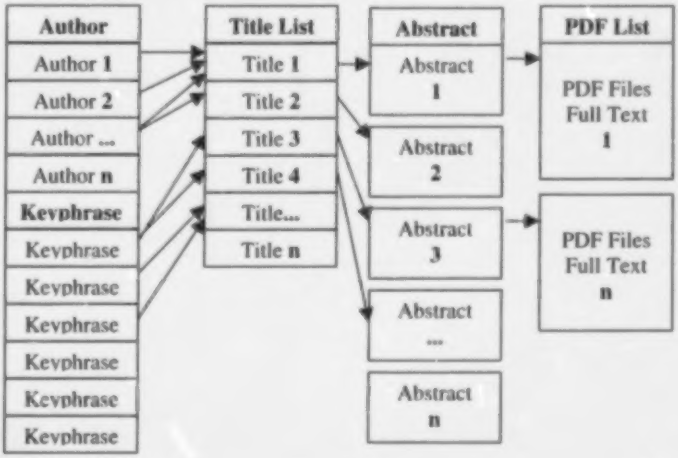

Fig. 4: Data structure

4 Discussion

The SL/AM-IT CD-ROM meets both goals established in the project; it allows complete access to large *corpora* of data and information related to service life and asset management, and its methodology] can be modified to suite similar *corpora*.

The SL/AM-IT CD-ROM addresses many of the search and retrieval problems identified at the start of the project: (1) it provides a repository for considerable information in the area of service life prediction and asset management and the methodology can be used for most *corpora* of knowledge; (2) the combination of the keyphrases and the inverted index provides quick and accurate retrieval of information for both novice and expert users, and (3) because of the portable nature of the HTML protocol, both CD-ROM and Internet applications are readily available.

"Extractor" provides objective, unbiased keyphrases that can be used by novice and expert alike for searching of the *corpora* of knowledge. The interactive user interface is simple-to-use and provides both the keyphrase search capabilities as well as inverted index searching. In addition, the user interface is easily recognized by, and is quite familiar to, a large percentage of Internet users.

The system design and data structure are extremely easy to duplicate and to create for any domain *corpora*. All of the software used in the processing can be purchased commercially, including "Extractor". All the files used in the operation are text files and all the lists were created using standard database techniques and word processing software. Although there was considerable manual intervention in the creation of all these files, many of the operations could be automated.

One of the advantages of this HTML-based system design is the possibility to continually update the *corpora* of knowledge in the future by including future DBMC conference proceedings and other full text documents, alongside full text articles from previous conferences and related journals, where only abstracts exist currently.

5 Conclusions

This paper describes SL/AM-IT, a technology transfer tool using IT to serve large *corpora* of technical information to users. The two goals were achieved in the course of this project: (1) provide full access to a compendium of information, and (2) illustrate a methodology for data storage, data retrieval and technology transfer for other domains. There are two innovative features of SL/AM-IT: (1) a keyphrase index was created automatically using automated indexing tools, and (2) an intuitive, interactive interface accesses large volumes of information. SL/AM-IT is a valuable contribution to the service life and asset management, and to CIB W80/RILEM 175-SLM; it can be seen as a *corpora* of knowledge to be expanded in the future.

6 Acknowledgements

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PART EIGHTEEN

DESIGN SYSTEMS

245 PROJECT MANAGEMENT ISSUES IN REMOTE CAD OUTSOURCING

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Abstract

The paper addresses the management of CAD outsourcing over Internet. Recent advances in group ware and work flow management tools have made Internet based outsourcing of CAD and GIS production an interesting and potentially viable business prospect. The proliferation of web technology has created the opportunity to distribute work to remote locations (e.g. in developing countries) and thus add to the gamut of electronic commerce opportunities. In fact, recent surveys have shown that many Architecture/Engineering (A/E) firms are already engaging in outsourcing experiments. Many of these experiments have ended in failure, mostly because of lack of proper distant management capabilities and agreed enforceable Quality Assurance (QA) procedures. As a response to 'risky' open partnership outsourcing, companies have started to establish remote affiliated offices to bilaterally manage the outsourcing of projects. This closed partnership approach is deemed less risky as it allows local implementation of established production processes and company styles of the client. The paper deals with the challenges that both types of outsourcing practices pose to the management of remote collaboration.

Keywords: CAD, Outsourcing, Remote collaboration

1 Introduction

The European funded project CaribCAD (Collaborative Approach to the Realisation of Internet Based CAD) project is developing the basis to turn outsourcing of CAD production intensive projects into a routine business process. The project acknowledges that outsource jobs come in many different flavours, and that there are few proven cases that can easily be generalised to work in all situations.

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Present outsourcing in the A/E (Architecture and Engineering) industry ranges from the regeneration of old paper drawings in electronic formats (e.g. for optimal maintenance support, refurbishment and re-design) to the electronic storage of the built heritage for recovery, archiving and preservation. Other outsourcing opportunities exist in the input generation for GIS purposes and the preparation of renderings and VRML presentations of building designs.

CaribCAD focuses specifically on two cases, (1) the regeneration of existing paper drawings in CAD file format and (2) the support of communication needs in remote design collaboration. Both cases are demonstrated in PILOT projects, involving real life projects that are contracted between the European A/E firm (the client) and a CAD bureau in Latin America (the 'supplier' or 'CAD provider'):
Pilot 1: refurbishment of a hospital for which only paper drawings exist
Pilot 2: remote design of swimming pool and complex in Guyana

We will report on the progress of the CaribCAD project, with a focus on project management issues relating to distant collaboration, i.e. multi-social, multi-lingual, multi-time zone and multi-cultural co-operation. The challenge is to support the management of this co-operation by the right mix of group ware and workflow management techniques. The premise of the research is that the development of successful outsourcing will have to be based on an analysis of CAD production processes at both ends, eventually resulting in one single process definition shared and owned by client and supplier. Such process definitions are to be captured in formal process models, which typically contain a set of generic processes defining recurring operations in the generation, communication and revision of CAD drawings. Each particular project analysis (in an open or closed partnership contract setting) is consequently based on this set of generic sub processes with customised QA and document routing procedures built on top of them. The CaribCAD approach towards achieving these goals is explained in the following sections. Although contracting issues are recognised as very important, CaribCAD is not dealing with these issues as such, but rather providing and benchmarking the technology that could underpin outsource partnering contracts.

2 Requirements analysis

Many A/E firms have tried the outsourcing of CAD production work such as regeneration of CAD drawings, rendering and visualisation. It usually concerns low volume, incidental work with low demands on downstream re-use of the work delivered by the remote partner. Working relations and contracting are based on incrementally increasing work assignments. This establishes the necessary trust that the remote partner can deliver on time and achieve the required quality. This one-on-one outsourcing practice clearly has its limitations when it comes to high volume outsourcing with high quality demands. Moreover, as the business profit in outsourcing is mainly in the 'peak shaving' of CAD operator workforce fluctuation in the client's office, outsourcing becomes an inherently time critical job, which can not rely on the availability of the established and trusted supplier alone. To the contrary, large jobs will have to be outsourced to a group of suppliers simultaneously following a quick and open bidding process.

A requirements analysis (CaribCAD 1998) was done to make the needs of the outsource partners explicit. Fig. 1 shows the distinction of the two major types of outsourcing partnerships that were established in the requirements analysis.

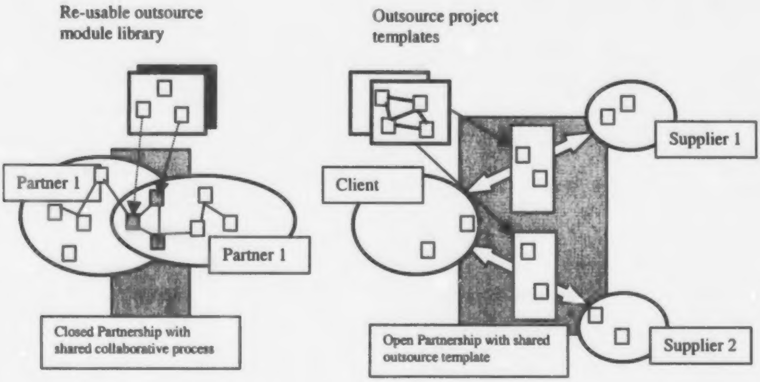
Re-usable outsource module library
Outsource project templates
Partner 1
Partner 1
Client
Supplier 1
Supplier 2
Closed Partnership with shared collaborative process
Open Partnership with shared outsource template

Fig. 1 The characteristics of closed and open outsourcing partnerships

Both types of partnerships pose distinct requirements on the type of group ware and WFM that is able to support them adequately. The production oriented open partnership stresses remote instruction, performance testing and reliable (rigid) project execution with flexible specification and enforcement of QA procedures. The collaboration oriented closed partnership stresses flexible project execution supporting autonomous actions by both partners and delegation of responsibilities between partners.

Fig. 1 (left part) shows how collaborative partnerships may be supported by a library of modules that can be re-used whenever applicable in a certain project setting. A module will typically contain task definition, work flow aspects and communication patterns for recurring ‘collaboration events’. A module is spceific to the partnership and owned and maintained by the partners.

The right part of the figure shows the way in which open partnerships may be supported by template models of classes of outsource projects. The template model is not typical to the partnership but to the type of project. The requirement is that templates are defined such that they can be reused in similar projects with a different client and different suppliers.

A very important and underestimated aspect of CAD production outsourcing is the quality assurance (QA) of the generated CAD drawings. This subject is outside of the scope of this paper, but it needs to be stipulated that the generation of proper QA procedures is a major component of any re-usable module or template model. The lack thereof in present outsourcing practices has led to many failures and loss of investments. In fact, the embodiment of proper QA procedures and total quality management (TQM) in general, has formed the prime motivation for the CaribCAD initiative.

Among the general requirements of an 'outsource package', we suffice to mention that tools must operate in a collaborative group environment, allowing specification of group members, their authority and security settings, etc. All group members are connected by email, and have (permanent or dial-up) access to the Internet for file transfer and web browsing. The remote users should have minimal specialised software, typically a WEB Browser and a mail tool The tools must allow easy specification of a tailored 'project information repository' enabling all group members to have flexible access to all project documents. The repository must support versioning and setting of user permissions for browsing and editing. An adequate group ware solution must be selected to meet these requirements.

The tool set must allow the generation of a project specific central task repository that enables process building and enactment through the assignment of tasks to group members and the monitoring of execution The model underlying the 'workflow execution and support' should have a graphical representation transparent to all users.

Based upon these requirements the implementation by the CaribCAD team adopted a three layered approach to the creation of a collaborative working environment,

- Communication
- CAD file and Document Management
- Collaboration and Work Flow

For the first two layers, the strategy was adopted to create an Intranet within the Internet building upon the Microsoft Exchange Server environment. This allows each remote partner to access their group-ware environment through a simple Web browser interface using standard HTML protocols and at the same time high levels of sophisticated development at the server side. The end result is full support for mail, shared calendars, databases and tasks with no sophisticated software configuration on the client side, essential when reliable and quick deployment to new remote users is essential. The following sections will focus on the third layer.

3 Template models for outsource projects

It is one of the goals of the present research to develop generic models for sets of similar outsource projects. Such a generic model will serve as a 'best practice' template for a particular type of outsourcing project. CaribCAD is developing three project templates, i.e. for the two PILOTs described before and an additional one for a particular type of GIS input/analysis collaboration. In (Augenbroe and Lockley 1998) the general approach to establishing joint agreement on an outsourcing project of the Pilot1 type is explained in detail. The approach is based on a modelling effort that spans three clearly defined stages:

a) First stage model: web enabled heuristic model

A 'neutral' representation of the workflow and document flow capturing the procedural flows of tasks and their dependent documents. This stage of the modelling process is 'web enabled', i.e. the model is built as a web model that can be browsed by all (prospective) partners and decompositions of tasks can be traversed. An example top level model for Pilot 1 is shown in Fig. 2. The example shows the three top-level tasks:

1. Provide instruction (exchange and reach agreement on instruction set)
2. Do performance test (a designed test to ascertain worker skill level at the supply side and agree on QA procedures)
3. Conduct actual project ,starting with the negotiation of the contract, and ending with the delivery of the CAD files

The models contain all the documents that are either externally provided or generated in project tasks and routed to other tasks. Each task, decomposed subtask, and document can be inspected by traversing hyperlinks. Associations between documents and tasks can also followed. At the lowest decomposition level, atomic drawing tasks are encountered that relate to the CAD file and layer structuring that is encapsulated in the set of manuals and other instruction documents supplied by the client..

This stage of the model makes all 'communication requirements' and task dependencies explicit. The model allows each organisation to verify quickly whether the template adequately supports the type of project they seek to outsource. Furthermore, the model can be used to perform risk analyses, e.g. looking at the critical process factors such as the demands on resources, transmission speeds, expected operator skill, etc.

b) Second stage: IDEF-0 activity model

The second stage formalises the model into an activity and information flow diagram, reflecting the functional aspects of the project. The activity modelling language IDEF-0 is used for that purpose. IDEF-0 formalises the semantics and creates an important link between the easily accessible stage 1 models and the formal process built in stage 3.

c) Third stage : WFModel .

In this stage the activity model is projected on a collaborative group setting, taking all operational and dynamic issues, actors, deadlines, authorities, resource allocations, etc. into account. The WFModel defines precisely what is done, by whom and when. Fig. 2 shows the three modelling stages during the process building stage. It is important to note that in the runtime workflow environment the models of the two previous stages are accessible from within the WFModel. For instance, hyperlinks can point from a particular workflow item in the WFModel to the corresponding task on a web page. This page may contain links to particular instructions and provide guidance for the group member who is assigned the work flow item. Moreover, during the execution of a project, the linked pages would be maintained to always contain up to date instructions.

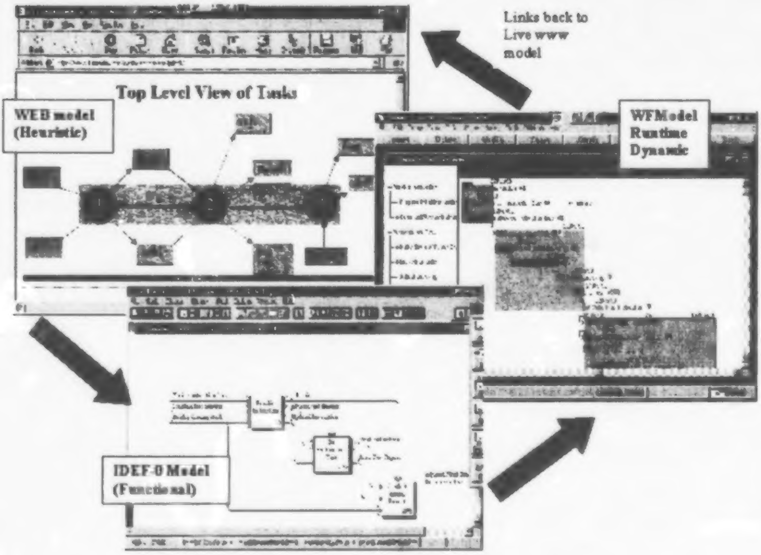

Fig. 2: Three stage modeling strategy of outsource project: three different versions of Pilot 1 project

The three modelling stages provide the framework for describing the sequences of tasks and protocols to work collaboratively. Without such a framework, any integration will be informal, ad-hoc and unreliable. Existing practice is for each company to have their own internal and informal workflow models and for them to agree, on a project by project basis, the interface points where information is exchanged. By the creation of template WFMs for inter-company exchange, organisations can enter into new and repeat collaborations more effectively and with improved levels of quality control.

The methodology for definition of the template models is de-facto based on the Information and Business Process perspectives identified in (Medina-Mora et al. 1992). The business process perspective is given to the Activity models by moving the focus to client satisfaction, in this case through the definition of quality assurance mechanisms and procedures.

The next section deals with the choices that have to be made in terms of most suited workflow paradigm and type of run time support in each particular case.

4 Workflow management issues

WFM is a basic ingredient of CSCW in general. CSCW is defined in broad terms as computer support for groups (Greif 1988), delivered through software defined as GroupWare often referred to as Workgroup Computing. There are many flavours of CSCW and (Schäl 1996) proposes that these flavours are characterised by the degrees of "Information Sharing" and "Activity Synchronisation" they contain. He identifies three distinct forms of CSCW, "Co-operative working", "Collaboration" and "Co-decision" and sustains that the predominant technique for co-operative working is activity synchronisation and the predominant technique for "Collaboration and Co-decision" is information sharing. He further states that it is essential in the early stages of CSCW implementation to determine the appropriate flavour to adopt and identifies the specific features that are required to support these three methods of working, the following have been adopted in the implementation of the CaribCAD Pilot project environment:

Co-ordination	- Distribute and select easily messages - Link messages into conversations - Record and clarify messages/conversations with their status
Collaboration	- Structure information in a way that reflects how it was created - Access information with different rights depending on members' role in process - Support questions and answers about on-going task
Co-decision	- Share all information that is useful for a decision to be taken - Share and make comparable the decision criteria - Share the decisions already taken - Manage conversations for possible clarification and orientation

Inspection of the Pilot projects indicated that Pilot 1 is more of the 'co-operative' working type where each participant in the process plays a role and acts in a well-planned sequence of activities to achieve an outcome. Whereas Pilot 2 is oriented more towards "Collaboration and Co-decision", whereby individuals work together and joint decisions have to be taken.

Accordingly different approaches have been adopted for the development of the CSCW environment for each pilot. Pilot 1 is synchronisation biased, where there is limited information sharing and the outsourcing partner is executing a pre-planned sequence of tasks largely initiated by the main partner. Pilot 2 is information sharing biased with limited co-ordination as each organisation is operating largely autonomously, both parties raising and responding to tasks on an ad-hoc basis as definition of the final outcome is agreed. The differences between these two pilots are highlighted in the types of workflow models that are generated.

4.1 Application of WFM technology

A workflow is a unit of work that happens repeatedly in an organisation, every workflow has a customer and involves the movement and tracking of people, documents, products or information. There are two distinct types of WFM technology, e-mail driven and database driven, reflecting the development from either a communication system which acquired embedded WFM or a WFM system which acquired communication support. According to (Swenson 1994) the e-mail driven systems have several disadvantages, the email inbox is private, once mail in user inbox it cannot be moved except by the user.

Both approaches are being examined in CaribCAD through the selection of different workflow engines, Keyflow™, which is e-mail based and KWS™, which is database centric but is also able to support notification driven work flows.
Fig. 3 illustrates the overall system architecture of the Pilot 1 implementation.

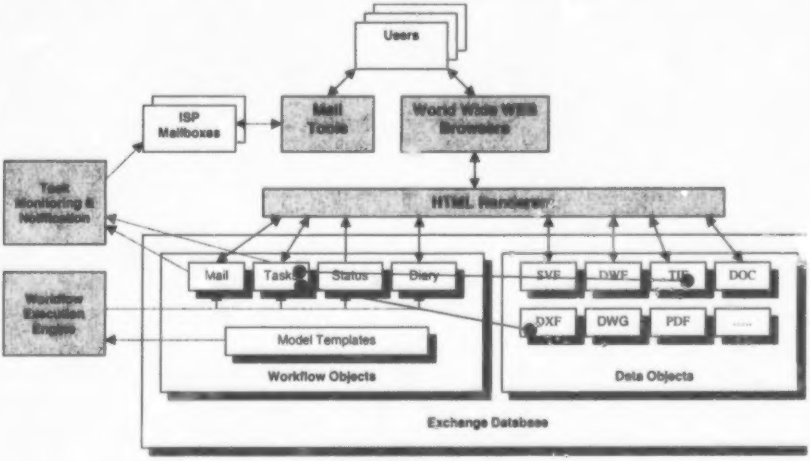

Fig. 3 CaribCAD system architecture

This architecture was derived from the requirements analysis discussed in section 2. It comprises a data repository built on top of the Microsoft Exchange Server which provides a storage mechanism for all objects such as documents, CAD files, tasks, mails etc. together with the relationships between these objects. The object model holding this data is based upon the Collaborative Data Objects Model and the interfaces to these objects are compliant with the MAPI standard. The following briefly describes the operation of the CaribCAD environment.

Workflow Models are developed using a graphical design tool that is embedded inside Microsoft Outlook, the output of this tool is a specially formatted e-mail message that is stored as a workflow template that can be executed many times. Fig. 4 illustrates a simple Keyflow generated workflow from Pilot 1. Each node in the workflow has a role and a time scale, together with the data required for its performance. The workflow is initialised through a WEB forms interface, which supplies the relevant data for that particular execution; roles are substituted by actual performers, CAD files and other documents are attached. Once executed the state of the flow is monitored and progressed by the WFM server, a separate application. As each node is processed, mails and tasks are placed in users task list on the server. A separate application monitors these task lists and as tasks arrive sends a notification mail to the user's normal (local) mailbox. When a user receives a notification they use the WEB browser to access remotely the CaribCAD Pilot project server and view their tasks and associated data. These tasks are rendered on the server into HTML using Outlook WEB Access and other server side scripts. This allows quite complex information to be presented in the client's browser and limits the amount of Internet traffic required. For example, the user can browse and select through a range of CAD files, each of which may be several megabytes in size without downloading the entire file. This is achieved through server based applications which translate the graphical content of the CAD file into HTML.

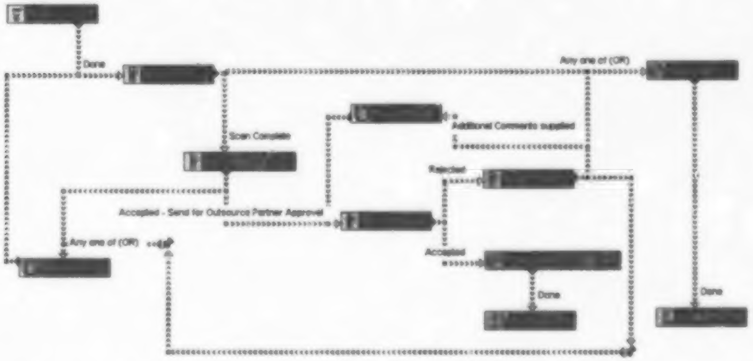
Done
Any one of (OR)
Scan Complete
Additional Comments supplied
Rejected
Accepted - Send for Outsource Partner Approval
Any one of (OR)
Accepted
Done
Done

Fig. 4 Typical workflow template

4.2 Workflow modelling formalisms

Although there are now emerging software environments which are moving towards fourth generation of WFM technology as defined by (Abbot and Sarin 1994), it is clear that there are two distinct types. (Schäl 1996) defines these as "workflow systems" and "Procedure processing systems", the key difference being that the latter has no explicit and logically distinct workflow model, only a specification model.

The importance of the model has been highlighted in case studies and serves to make the execution of the workflow transparent to the participants.

At present the models for Pilot 1 are being translated from procedural models to the activity models and it is too early to determine if the message based workflow paradigm will be successful, but initial tests look promising. Analogously, the Pilot 2 models are being translated in the database centric work flow environment of KWS

5 Conclusions and further work

One of the ambitions of the CaribCAD project is to establish proven cases of successful CAD outsourcing and develop a CSCW outsource package for their support. Re-usable models for two significant classes of outsource projects have been developed with input from leading A/E firms. A three stage development track of the template models has been proposed, going from (1) heuristic procedural models via (2) activity models to (3) the ultimate CSCW models that can be executed to support the work flows in an actual project. It has been shown that the different templates or project modules in different partnership settings may require different workflow paradigms and tools to support them.

The remaining work in the project will be dedicated to the benchmarking of the models in a CSCW environment with real life pilot projects. The close monitoring of the pilots will show whether the ambitions of the project to provide generic support to outsourcing can be reached.

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246 IMPLEMENTATION OF A DYNAMIC INFORMATION SYSTEM FOR DESIGN

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Abstract

This paper reports an implementation of the conceptually most important features of the BAS•CAAD information system, and the use of this implementation to create models of different levels of generalisation in the construction context. The foundations for the BAS•CAAD information system, which have been presented in an earlier paper, are briefly described. It is a dynamic information system for design, built on a generic ontological framework. The system supports the definition of classes in different levels of universality; the classes may originate from different standards or the individual designer, and allows a free combination of attributes.

Keywords: CAD, design, dynamic schema evolution, information systems, object oriented modelling, product modelling

1 Introduction

Many approaches of product modelling focus only at modelling, and seem to overlook the process of creating the models. The most outstanding feature of this process is that the information changes and evolves over time, not only in quantity but as well semantically. This would make it hard to use a product modelling system based on a fixed classification schema in the earliest, most dynamic phases of design, since the fixed schema would be at odds with the evolving semantics of design.

This paper presents the author's work of implementing a prototype information system, which has been constructed from the basis of the theoretical investigations of the BAS•CAAD research project. The project aims to find solutions to both the problem of modelling, and to the need to reflect and support the evolving nature of the design process. The theoretical foundation of the project was initially developed by Dr. Anders Ekholm, and has been refined by him and the present author as part of the BAS•CAAD project.

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1.1 Information systems for design

Information systems are computer based systems that support handling information, e.g. during problem solving. A more thorough discussion of information systems for design can be found in (Ekholm and Fridqvist 1998). There, we defined that information systems for design must: 1) support representing objects in the domain of interest, 2) be able to communicate with other software, 3) support defining the design goal, and 4) have a dynamic object structure.

Most proposals for product modelling software focus on the first two requirements. To be useful not only for describing the results of the design process, but as a tool in this process, an information system for design must have all properties mentioned above. This is discussed in e.g. Eastman and Fereshetian (1994), Eastman, Assal and Jeng (1995), Galle (1995), Junge, Steinmann and Beetz (1997), Leeuwen and Wagter (1998), and Ekholm and Fridqvist (1998).

2 Foundations for the BAS•CAAD information system

The BAS•CAAD information system is intended to cover all levels of generalisation of modelling in the construction context, from international classification standards to specific buildings. It is built on a generic ontological framework, with the object classes *thing class*, *relation* and *unary attribute*, and it supports generic design operations, like generalising and specialising, aggregating and decomposing, and adding and removing attributes (Fridqvist and Ekholm 1996).

The BAS•CAAD ontological framework allows models to be multi-contextual; that is, several contextual views can be co-ordinated in one model. The foundation for multi-contextuality is aspect views, as described in (Ekholm and Fridqvist 1998). However, although multi-contextuality is inherent in the BAS•CAAD object structure, it has yet to be implemented as an observable feature in the user interface.

In Fig. 1 the ontological framework is depicted as an EXPRESS-G diagram. The figure differs from the one in (Ekholm and Fridqvist 1998) in that the entity Attribute is now named UnaryAttribute. In addition, the superclass BAS_CAAD object is removed.

The BAS•CAAD information system is based on a similar object oriented view as object oriented programming languages. In its present state, however, the BAS•CAAD information system does not support definition of the objects' behaviours (see section 3.1). For simulation purposes, a modelling system must enable defining the behaviour of the objects. The present development of the BAS•CAAD information system is intended to show how a system that describes classes of concrete things can support design; simulation modelling is not supported, although such an extension is possible.

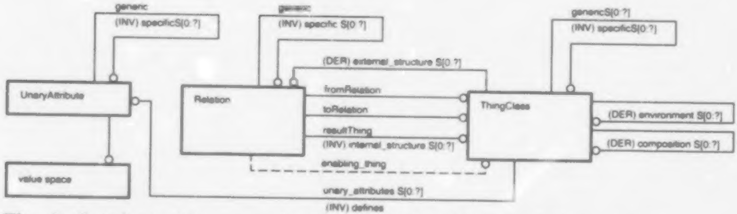


Fig. 1: Ontological framework of the BAS•CAAD information system

2.1 Design statements and attributes

Artefact design can be characterised as making statements about the designed thing and the 'satisfactory situation' that the design is to support (Ekholm and Fridqvist 1998). An information system for design should accordingly at least be able to record such statements. The statements, of course, need not be verbal. Also 2D drawings or 3D models or parts thereof can be treated as statements. The BAS•CAAD information system is designed to collect such statements and to support analysis and communication of them.

Note that not all designer actions result in new statements in the meaning used here. Some actions change or delete already present statements. Thus, statements are not identical to the moves Schön discussed. Schön used the term *move* for any physical or mental activity the designer takes regarding the design task (Schön 1983).

The attributes of the entity ThingClass in Fig. 1reflects that it can be defined as a 6-tuple of sets of attributes, T = (T_G, T_C, R_I, T_E, R_E, A_U), (Ekholm and Fridqvist 1998). Given the BAS•CAAD ontological framework, only seven different types of statements are possible. They correspond to creating ThingClasses, and to adding attributes to the six sets mentioned above.

1. There is a kind of things, called X.
2. An X-thing is a kind of Y-thing (= kind X is a subkind or specialisation of Y).
3. An X-thing is composed by a C-thing part.
4. An X-thing is internally structured, so that any part of kind P1 is related to any part of kind P2 by an R-relation.
5. The environment of an X-thing includes an E-thing.
6. An X-thing is related by an S-relation to any E-thing in its environment.
7. An X-thing has the unary property Q.

A consistent collection of correct statements defines a model through the three basic classes of the ontological framework in Fig. 1. However, these classes are not suitable for storage of design information, since all connections between objects must be established. The trouble with this is that some connections might imply statements that the designer would not intend. In particular, some things are used in numerous different environments, and it would not be desirable to have to include all these environments in the definitions of thing classes like 'bolt' or 'nut'.

Instead, we have found that all information necessary for the creation of such a schema is contained in a consistent set of design statements, as related above. Thus, the schema in **Fig. 2** has been developed to provide the data structure to be implemented. Design data are stored in instances of *ThingClassDefinition*, which collects instances from the six subclasses of *Attribute* that correspond to the six different kinds of attributes, see **Fig. 2**. The classes *RelationDefinition* and *UnaryAttributeDefinition* define relations and unary attributes, and ensures that attributes referred to in several places are identically defined.

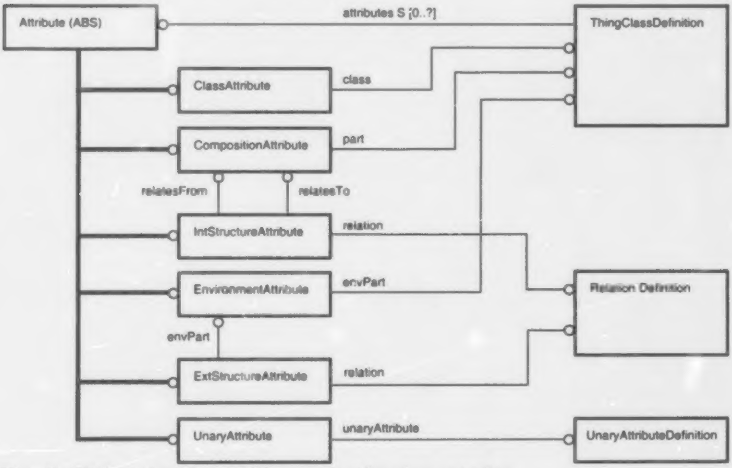


Fig. 2: Object structure of the current implementation

2.2 Example

To describe a thing in the BAS•CAAD system is to define thing classes for the thing and its parts, and the attributes that characterise those things. Fig. 3 displays a brief example of how an ordinary table may be described. The presentation is not an actual printout from the prototype software, although a similar syntax is used for files.

ThingClass *table*
  CompositionAttribute *tableTop* Cardinality *1*
  CompositionAttribute *tableLeg* Cardinality *4*
  InternalStructureAttribute *tableLeg isConnectedTo tableTop*
  InternalStructureAttribute *tableTop isConnectedTo tableLeg*

ThingClass *tableLeg*
  ClassAttribute *woodenBar*
  EnvironmentAttribute *tableTop*
  ExternalStructureAttribute *isConnectedTo tableTop* In *table*

ThingClass *woodenBar*
  UnaryAttribute *material* ValueSpace *wood*
  UnaryAttribute *shape* ValueSpace *bar*

Fig. 3: Thing class definitions

Table legs obviously are functional parts of tables; a wooden bar is characterised by its material, and its shape.

	House	Palce
Define attributes	man-made provides dwelling	Kind of House
Inherent attributes		man made provide dwelling

Fig. 4: Defined and inherited attributes

2.3 Other features of the object structure

Besides generating and maintaining the object structure, the prototype currently supports a simple schema for object identification, inheritance and specialisation of attributes, and class libraries. Additionally, class subsumption is planned to be implemented.

2.3.1 Object identification

The BAS•CAAD information system for design allows thing classes to be defined by references to predefined libraries (see section 3.3). Such a mechanism requires that libraries and classes can be unambiguously identified, in order to ensure that the correct libraries are used. The current version can identify objects within a library, but there is no secure identification of libraries. The development of such a mechanism is a task for database specialists and international standardisation organisations, and outside the scope of this phase of the BAS•CAAD research project.

2.3.2 Attribute inheritance

Class attributes indicate a more generic kind, also called a superclass. All statements defined for the superclass are also valid for the subclass; the attributes of the superclass are inherited attributes of the subclass. An example: the class House has the attributes 'man-made' and 'provides dwelling'. If Palace is defined by the attribute 'kind of Building', Palace inherits the attributes 'man-made' and 'provides dwelling' (Fig. 4). A mechanism for attribute inheritance has been implemented.

2.3.3 Attribute specialisation

With the above set of attributes, however, the Palace class doesn't reflect that a palace is a specific kind of house. This type of difference can be defined in to ways; either by adding a new attribute to the specific class, or by specialising an inherited attribute. Which way to choose is a question of clarity in modelling and usefulness of the model; se Fig. 5 for a illustration of the differences of the two methods in terms of sets.

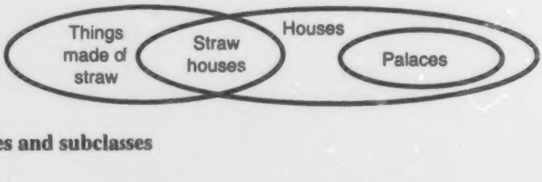


Fig. 5: Classes and subclasses

	House	Palace
Defined attributes	man-made provides dwelling	kind of House *provides luxurious dwelling*
Inherited attributes		man-made provides dwelling

Fig. 6: Attribute specialisation

In this case, we have chosen to specialise the attribute 'provides dwelling' into the more specific 'provides luxurious dwelling', and to define the class Palace with the specialised attribute. A mechanism for this has been implemented. The new attribute is defined in the Palace class, where it substitutes the inherited attribute 'provides dwelling'(Fig. 6).

2.3.4 Class subsumption

Description logics (see next paragraph) provide a mechanism called subsumption. This could be described as the inverse of inheritance, since it answers what superclasses a given class has according to its set of attributes. For instance, if a thing Bungalow has the attributes 'man-made' and 'provides dwelling', then it is subsumed to be a kind of House, i.e. the class Bungalow is a subclass of the class House. Subsumption is not currently implemented in the BAS•CAAD prototype system, since it would make implementing inference more complicated. However, since subsumption could arguably provide a powerful tool for case retrieval, it will probably be implemented in a future version of the BAS•CAAD system.

Description logics (DL) is a field within artificial intelligence research. It aims to develop mechanisms for describing concepts, and to automatically classify concepts. DL is based on first order predicate logic, and is DL systems implementations are usually similar to programming languages (Lambrix, 1996). Although DL is similar to the BAS•CAAD approach in many ways, it seems that it cannot serve as the base for a design information system. This subject is outside the scope of this paper, but will be further developed in a future publication by the present author.

3 The BAS•CAAD prototype information system

The prototype is intended to study the feasibility of organising an information system for design based on systems theory. It should also be dynamic in respect to the possibility for the user to define new class concepts in the conceptual schema, and to classify model instances.

The current implementation has been preceded by many earlier attempts. The foundation has in all cases been the concepts *system* and *property*. The aim of the BAS•CAAD project is to support expression of designed objects through these concepts in a computerised database. Thus, all versions of the software have sought to implement these two terms as object classes.

It is intended to display some features we consider important in an information system for design, but it is not intended for productive design work. The current version is centred on building symbolic schemas for concepts referring to things, and lacks most of the abilities to specify metric values necessary for a production tool.

3.1 Smalltalk

The BAS•CAAD prototype information system is currently implemented in Smalltalk under the Macintosh operating system. The reason for choosing the Smalltalk computer language was that it is object oriented, and that it supports explorative program development.

In product modelling, products are structured as objects that are assembled of objects in several levels. This makes it natural to choose an object oriented programming language for implementing such a system. Object oriented programming is based on the concept of objects that interact through sending and reacting to messages. Objects are defined through classes, which define the structure and behaviour of the object. The behaviour is the collection of various responses an object is capable of, and it is defined through pieces of software code, that in Smalltalk are called methods. Each kind of message that is 'understood' by an object corresponds to one method, which handles that particular kind of message. Some methods return answers, others just change the object's internal state.

In explorative program development, the software needs only to be partly defined before it is executed and tested. Thus, experimental solutions can be tried and kept if successful; otherwise, they are discarded. This way the final software solution is obtained though an exploration. In Smalltalk, code segments can be run and tried directly, without any time-consuming compilation or linking procedures. Actually, Smalltalk allows the programmer to change the code while the software is running, thereby relieving the programmer from repeatedly punching in lots of test data. This is not possible in C++, a popular programming language that also supports object oriented programming.

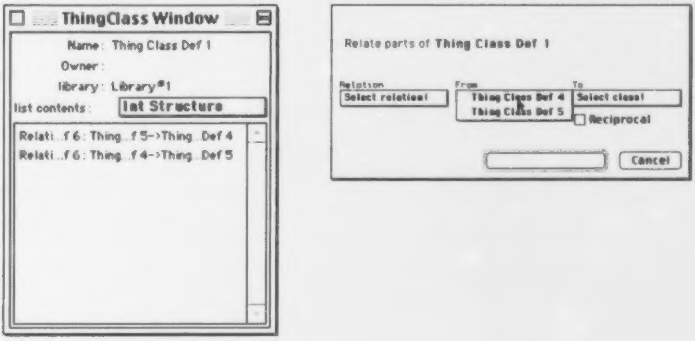
Smalltalk is profoundly object oriented; every concept is treated as an object class. Thus, in Smalltalk it requires an effort to not be object oriented, as opposed to C++. A drawback with Smalltalk is that the resulting programs do not run as fast as those created with e.g. C++.

3.2 Implementing the system

The foundation for the BAS•CAAD prototype is the three concepts thing class, relation and unary attribute that are implemented through the corresponding object classes *ThingClassDefinition*, *RelationDefinition* and *UnaryAttributeDefinition*.

To create and manipulate these objects, some means has had to be created. Principally, there are two choices: a command line user interface or a graphical user interface (a GUI). In a command line user interface, the user types commands, and then usually hits a key to get the command executed. A command line interface requires developing a command line interpreter, a piece of software that can translate the command lines into software actions and input data.

A GUI can make it easier for the software developer by controlling the user's actions. The user controls the software via buttons, menus, text input fields etc. Thus, the software developer can restrict the user to input only such instructions or data that are valid, through presenting only such control objects that allow actions that are meaningful to the software in a given situation. A benefit for the user is that it is fairly easy for the developer to make the software self-explanatory through a GUI.



ThingClass Window

Name: Thing Class Def 1

Owner:

library: Library*1

list contents: Int Structure

Relati..f 6: Thing..f 5->Thing..Def 4

Relati..f 6: Thing..f 4->Thing..Def 5

Relate parts of Thing Class Def 1

Relation: Select relation!

From: Thing Class Def 4

Thing Class Def 5

To: Select class!

☐ Reciprocal

Fig. 7: Examples of user interface windows

Regarding these concerns, the choice fell upon a GUI as the method to interact with the software. Each of the object classes ThingClassDefinition, RelationDefinition and UnaryAttributeDefinition has a corresponding window class. The Smalltalk dialect used for the BAS•CAAD prototype (Smalltalk Agents, STA), provides generic classes of GUI components, such as windows, menus, buttons etc. These can be subclassed and modified to suit the particular needs of the software being developed.

In addition to the three classes of windows related above, which display the state of the model, additional windows have been developed for specific tasks, such as adding different kinds of attributes to thing class definitions.

Windows communicate with the corresponding model objects through messages. Each user interaction with a window causes at least one of the window's methods to be executed. This results in messages being sent to the model object, which responds with the appropriate actions. Finally, some messages are sent from the model object back to the window, to ensure that the window reflects the new state of the model object.

Most of the work with the development of this prototype system has been, and continues to be, to decide how to obtain the desired functionality. To perceive a user action in the terms of objects exchanging messages is a complex task. One particularly difficult question is to decide what object is the agent, and what objects are acted upon. The reason for this is that many objects may be involved in the execution of one user action, with many messages exchanged. If the resulting web of such message interchanges is too entangled, the programmer is likely to get lost. Additionally, there is a need to make the software code as intuitive as possible to any future programmer (which, incidentally, often is the same person, but a couple of days later).

3.3 Libraries

The use for the BAS•CAAD system is to record information about concrete things through the three concepts thing class, relation and unary attribute. The task for the user is to define what different kinds of things that compose the part of reality that is to be modelled, and the relations and other attributes that characterise such kinds of things. Then, the BAS•CAAD system can be used to record these definitions.

Acknowledgeably, defining a coherent conceptual understanding of the concrete world is a very demanding task. To allow the BAS•CAAD system to be used in normal design situations, pre-defined well-considered schemas of thing classes has to be provided for use as libraries, from where the designer can fetch definitions to build up his design database.

The current BAS•CAAD prototype supports such class libraries. Objects in libraries can refer to objects in other libraries, so that hierarchies of libraries can be created. This feature is implemented to try a mechanism that would allow international and national standardisation organisations to create generic libraries. Building material providers and others can then create intermediate level libraries that ultimately can be used as references in specific building projects.

The concept of class library has been generalised, so that library is the sole format for databases and files. Thus, the work of any level of specificity can be the foundation for further specialisation. For instance, it would be possible to use the project file from a window designer as a library file in a building design project without any reformatting or reclassification.

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247 TOWARDS MODEL BASED DESIGN — A CASE STUDY: THE MODULAR DESIGN SYSTEM

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Abstract

The U.S. Army Corps of Engineers has developed a tool called the Modular Design System (MDS) to assist design professionals in the processes of planning, design, and construction document preparation for repetitive facility types. The use of early versions of MDS has demonstrated a reduction in time by nearly two-thirds typically required to design and award a construction contract. Initially developed to support Army Reserve Training Centers, the USArmy Corps plans to expand its use over a wider range of repetitive facility types.

The current implementation is a hybrid document/model approach consisting of electronic drawings linked by an external database. Data consistency issues associated with this architecture limit its scalability. To meet expanded requirements, the USArmy Corps is developing a model based information approach utilizing emerging commercially available object based CAD systems. This redesigned information infrastructure marks a fundamental change from an implicit to an explicit model-based representation.

Three key capabilities make MDS a powerful tool. First, the ability to capture and reuse corporate design criteria at the architectural function level. Second, it provides an integration framework for engineering analysis. Third, it manages and integrates the contract document production.

The underlying MDS information infrastructure will move towards a model based approach. Future work will focus on collaborative processes such as conflict resolution and design review. Additionally, MDS offers the opportunity to transfer an information rich model downstream to operations and maintenance.

Keywords: model based design, facility design, object-oriented modeling, design criteria capture and reuse, integration framework, construction document production, computer aided design (CAD), industry foundation classes (IFC)

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1 Introduction – MDS today

The Modular Design System (MDS) is a computer software add-on application to a commercial computer aided design (CAD) system that supports the planning and design of facilities (Bonham 1997). Working from pre-engineered modules (architectural functions), designers can quickly assemble design solutions. MDS supports a spectrum of facility types to varying degrees of completeness. When a facility type is decomposed to the reusable function level, many similarities between facility types become apparent. Functional overlap between facility types can range from 50 to 95 percent. Additional building types can easily be supported through the addition of new modules (functions) that support their unique requirements. Currently used by the Army Reserve and National Guard, MDS is being deployed for military construction and work for other government agencies.

MDS supports design activities from project requirements to construction document development. Each module contains information related to the design criteria, cost and specification requirements of its particular architectural function. This provides for a more accurate cost estimate and reduces the possibility for errors and omissions between drawings and specifications. Utilizing a charrette process, owners and users can more accurately identify facility requirements and transition into design production seamlessly. The result is a reduction of delivery time by as much as two-thirds, reducing the gap between identifying the users needs and satisfying them.

The current version of MDS (2) is implemented on top of MicroStation 95 using the MicroStation Development Language (MDL) (Bentley 1998). The technique utilized to capture information about design components is to link MDL primitives and graphical elements through resource files. The resulting building models are contained in a collection of drawing, relational database and ASCII "resource" files. Additionally, the model can be exported into Microcomputer Corps of Engineers Automated Cost Estimating System (MCACES), which associates cost data with MDS components.

While the current implementation has demonstrated success within the Army Reserve and National Guard construction program, expanding requirements warrant additional functionality. The main barrier to addressing these requirements is at the data level. The association between graphical elements and data in resource files has to be explicitly maintained. Each piece of data requires a unique software routine to maintain data integrity. This limitation exists for two reasons. First, the technology available at the time of development would not support a more robust implementation. Second, MDS was originally developed to support only two facility types, Army Reserve and National Guard training centers. A change in the underlying data infrastructure is required.

2 MDS 3.0 - Future framework implementation

Today's facility design process results in a number of application-specific facility models. Transferring information from one model to the next requires recreating the desired information by hand. Often the information does not exist in a computable form, rather, it can only be identified through human interpretation of lines and arcs. A robust engineering model is a sufficient informational model of the facility design and requirements supported in a computational environment. Such a model is important from a Corporate/Organization information management perspective. In addition, it opens the door for a design automation suite in which the appropriate level of information access and reuse can occur.

MDS 2 supports partial information reuse through a set of linked graphical elements, resource files and databases. While the current MDS 2 does not utilize a complete robust engineering model, the partial model information successfully allows reuse and adaptation. Users can actively manage design information at the functional level. This allows the information to be managed and reused corporately. It provides a means to maintain a consistent level of quality and reduces costs of design, acquisition and maintenance. But the current approach is ad hoc and fragile.

A change to an implementation framework is necessary within which applications develop the robust engineering model (Pree 1995). Frameworks are the top-level abstraction utilized by software engineers. At the framework level business rules are defined which can interact with expected behavioral patterns. The software abstraction in a framework is an object class definition, our robust engineering model.

To meet the expanding requirements cost effectively and prepare for future capabilities; a new information infrastructure framework (MDS 3) is being developed. The needs to satisfy organizational and end user requirements will be met with two fundamental changes to MDS 2: a more robust engineering model and a strong implementation framework. The MDS 3 framework will provide a means to manage corporate information about design criteria, design solutions and life cycle facility models. It will be an information-modeling infrastructure which supports cradle to grave facility delivery and operation.

3 Design criteria – Representing explicit requirements

MDS 2 uses the concept of programs and functions as the principle way to manage design requirements and criteria. A program is a collection of functions. Functions contain explicit design criteria for specific activities. By accessing and utilizing specialized design criteria at the architectural function or activity level, MDS 2 streamlines the documentation process and quickly produces an initial design solution ranging from 25 to 90 percent complete depending on discipline, thereby reducing delivery time. As the MDS implementation migrates to an information management rich environment, program and function information can be captured and managed explicitly.

3.1 Functions

The concept of *function* plays an important role within MDS 2 and it is necessary for MDS 3. A function specifies the requirements of activity areas within a facility. Requirements can be either prescriptive or performance based (Donia 1998). The characteristics and behavior of specific design criteria for a particular function may vary by organization.

In MDS 2, there is a one-to-one correspondence between a function and a room (IdeaGraphix 1996). The MDS 2.0 uses a static implicit description of rooms that represent the completed room as a graphical collection. Information is included or excluded through implicit graphical elements contained within graphical groups that are layered to create a specific function/requirements set. Related information such as cost and method of construction is supplied by the function description in tabular form contained within resource files. Resources files and graphical elements are independent of each other and consistency is maintained manually. Figure 1 illustrates the composite completion of a typical office function within MDS 2. The discipline specific design criteria is captured in the associated graphical companion on the right. Information such as cost models and specifications are relational table based.

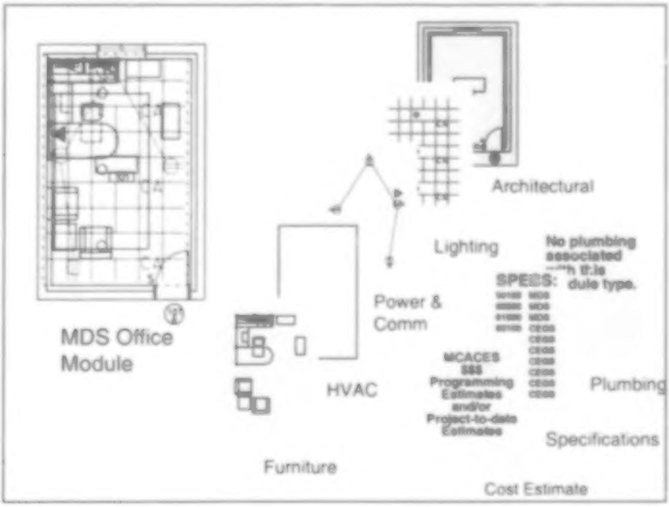

Fig. 1:Typical Office Function

3.2 Explicit representation

Moving towards a model based implementation, the collection of requirements for a function will be explicitly represented within MDS 3. With an explicit representation, the breadth of adaptability for a function to satisfy design criteria greatly improves across facility types and within localized solutions. The types of requirements that will be represented are:

- Occupancy – 24 hour schedule. An activity area may have established patterns of occupancy.
- Spatial – minimum/maximum area, width, length, and aspect ratio.
- Ventilation Heating – minimum required air changes per hour.
- Daylighting – minimum levels of daylighting that denotes windows or skylights.
- Lighting – task lighting levels at differing heights. Each function activity has specific lighting levels at a specific height.
- Physical Characteristics – specialty items. Examples of specialty physical characteristics could be handicap access, specialty equipment, or arrangements.
- Furniture – Layout and type. Each function can have specific furniture requirements both in arrangement and type.
- Finishes – colors, materials for each surface.
- Adjacency – A function may be required to be next to another function such as a lobby next to receptionist desk.
- Budget – The total cost budget allocated to this function.

As an example, the spatial requirements for MDS functions have been represented in SEED-Layout, a module of the Software Environment for Early Phases of Building Design (SEED) (Flemming and Woodbury 95). SEED-Layout uses the explicit representation to quickly generate design alternatives and solutions through a guided exploration metaphor. MDS 2 cannot represent the requirements or provide the resulting capability. Maintaining spatial relationships between functions is one of the many requirements driven design processes that needs to be managed explicitly within the framework.

4 The MDS 3.0 framework model

The framework model for design automation is comprised of three main components. The premise of the model is to capitalize on commercial applications as much as possible and focus on the information requirements that make the US Army Corps organization more effective. The most important component is the Facility Engineering Model Server. This layer provides the common model for all applications and the repository services that connect to a commercial database. The Discipline Interface Layer provides application program interfaces (API) that support domain specific activities such as structural analysis or HVAC design. The Support Services Layer is cross-discipline in nature. It supports corporate work-flow and information management requirements, including the ability to transform corporate design criteria into design solutions. It also manages construction document production.

4.1 Facility engineering model server

The Facility Engineering Model Server, as shown in Fig.2is the core component and provides the following capabilities:

- Database Connectivity
- Representation of Functional Requirements
- Artifacts
- Relationships
- Modules (specific configurations of Functional Requirements, Artifacts and Relationships)
- Version/Alternative Control
- Collaboration Mechanisms

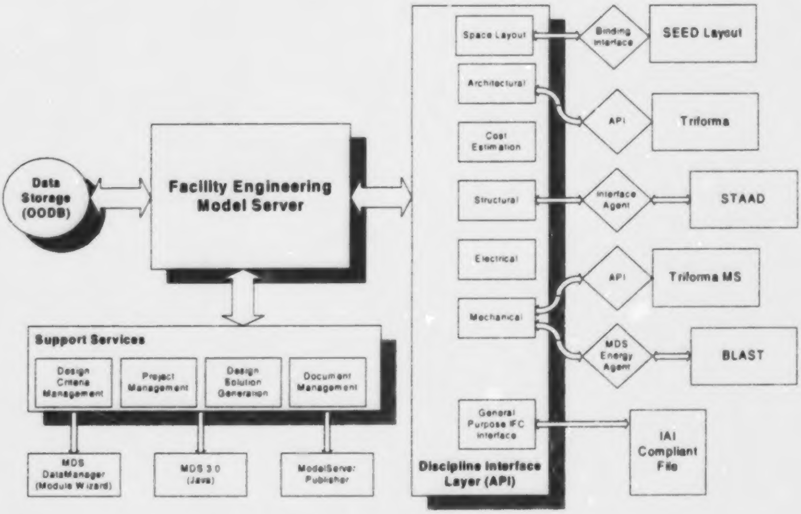

Fig. 2: Framework model

4.2 Support services

The set of services shown in the lower left of Fig. 2 facilitates the management of corporate information, processes and expertise (behavior and requirements). Support services are typically agent-based applications that provide selective domain expertise to facilitate manipulation of the engineering model. Agent applications are similar in nature to wizards used in applications like Microsoft Word. In this case, they apply corporate knowledge to facilitate design tasks. It is at this level that

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corporate lessons learned are incorporated into the design process, completing the feedback loop.

4.2.1 Design criteria management

This service facilitates the capture of organizational corporate information including specifications, cost models, requirement models, function models, document configuration and assemblies of building system components. Specialization provides a mechanism to distinguish the data-driven differences between differing corporate entities. For example, the criterion for the function *GenericClassroom* might apply to all corporate entities. However, the Immigration and Naturalization Service (INS) might decide that they have unique criteria for private offices. The INS would use a specialization of the *PrivateOffice* with their unique criteria modification. Additionally, the INS will need to define the requirements for a new functions that don't exist such as a *DogWash*.

4.2.2 Project management

This service supports corporate processes. Particularly important for collaborative design, it provides mechanisms to introduce change management and enforce corporate process control requirements. For example, this service can restrict access to a particular set of functions during space layout activities. This is also where collaborative communication protocols are defined. One agency might allow information to be broadcast to all design participants while another agency might require all changes to be channeled through the project lead prior to distribution.

4.2.3 Design solution generation

This set of services facilitates the application of corporate expertise (behavior and requirements), which act as a collection of Generate Agents. Each discipline and design activity requires a set of expertise to analyze the facility model and create solutions to specific design problems. These agents utilize the domain expertise and performance requirements to generate initial design solutions. These solutions include pre-placed components such as lights, diffusers, furniture, finishes and door types for a given function or activity. As with design criteria, the *GenericLighting* agent might be acceptable for the Corridor function in all facility types for all agencies. However, it is anticipated that specialized agents will be adapted to handle unique conditions such as architectural and plumbing requirements of an INS *DogWash* function. Specialization of generate agents enables a function to be adapted and reused, handling cases where specialized engineering is required.

4.2.4 Document management

This service will manage the information to produce the documents necessary for bidding and construction activities. It also facilitates new ways of interacting with the engineering model to improve customer coordination, design review and the construction process. Innovative techniques are possible by using the model to improve visualization and comprehension. The most important product produced from the end user's perspective is the Construction Document Set. These include graphic and non-graphic information (drawings and specifications). This service determines information requirements (e.g. number of drawings, specifications), collects and cross references information (e.g. schedules, details, sheet and drawing number), and publishes them (e.g. plotting or electronic bid sets).

4.3 Discipline interface layer

This layer provides the application interfaces and computational mechanisms to connect commercial applications with the Facility Engineering Model Server. Once initial design solutions for each discipline have been developed by the generate process, detailed design and analysis will be required. The degree and character of this activity will vary by organization, facility type, discipline and end user. Ideally, these activities should be supported by the principle commercial applications from which the design professional can choose. In practice, the applications depend on many factors including its functionality, data exchange capability, market penetration and cost.

4.3.1 Design and engineering domains

The following are the key discipline specific activities supported by the Discipline Interface Layer.

- Preliminary Design – Facility function requirements and preliminary layout.
- Cost Estimation – Building assembly models, work breakdown structure, unit price book.
- Architectural - Layout, massing, building enclosure, interior construction and interior design
- Electrical – Lighting, power and communications.
- Structural - Framing (vertical loads), lateral loads (bracing) and foundation (bearing).
- Mechanical – Energy analysis, HVAC, plumbing, fire protection.
- Furniture – Furniture layout, color schemes, open office arrangements.

4.3.2 Application interface mechanisms

There are several ways that a domain application can access the framework. Each method has a particular method for "delegating" responsibility for data integrity. Each application should be evaluated to determine how to best ensure data integrity.

- General Purpose IFC Interface – This service provides a file-based information exchange mechanism as defined by the International Alliance for Interoperability (IAI 1998). It will provide access to an increasing number of applications as support for this standard (and the standard itself) grows. The framework, in this case, assumes all responsibility for data integrity.
- Interface Agent - These are "wrappers" that serve as a translator between the model server and the application supported. Typically, an interface agent adds value to the design process by filtering, enhancing or adding information beyond that provided by the application. In addition, the interface assumes all responsibility for data integrity. The MDS Energy Agent and Structural Interface Agent are examples of this method.

- Binding Interface - A mapping approach useful for linking applications that have similar concepts. The interface provides an Interface Definition Language (IDL) that supports information exchange between the framework and application. In this case responsibility for data integrity may be shared between the interface and the application.
- Application Program Interface (API) – This method offers the tightest level of integration between the application and the framework. It allows applications to communicate directly with the framework. Since there is no intermediate software, the application assumes full responsibility for data integrity.

5 Document production

The state of the construction industry still requires construction documents as the final product of the design phase. MDS 2.X organizes, coordinates, produces and manages the construction documents. The documents are "extracted" from the collection of CAD files that together is the facility model. The proposed MDS 3.0 framework will still extract the information to produce the files, but the extraction will be a query against a computatable facility model. In addition, as the designer creates the engineered solution the facility model is developed without any additional effort on the designer's part and is therefore a by-product of the design process. Most architects and engineers consider their job to be the production of the documents, not the model. With this approach to document production, the facility model and construction documents go hand in hand.

In addition to the US Army Corps generated designs, a significant amount of the design work is contracted to private architectural and engineering firms. In the process of monitoring the work of both the in-house and contracted designs, the US Army Corps spends considerable time reviewing the work. Through this approach, the review process is streamlined because the requirements are explicitly represented and provide the preliminary solutions as the point of departure. Also, the facility model changes the nature of the review and understanding of the solution. Construction contractors will be able to view the facility model in non-traditional methods thus communicating the design intent more fully. This same capability will also facilitate the bidding process. The traditional process of poring over contract documents is replaced by reviewing the facility model itself. This better understanding of the facility should reduce the cost of the work by more accurate bidding and fewer errors to resolve. By changing the process of producing, reviewing, and estimating construction documents, the total quality will be greatly improved thereby minimizing costly change orders.

6 Benefits

Today's business environment is characterized by rapidly changing technology, heightened cost awareness and the aggressive measures to boost internal productivity. Designers want practical technology that enables them to get the job done. Smart use of automation technology will significantly improve design productivity, help designers apply and improve specialized engineering knowledge, and improve the product quality while building an information infrastructure that can be used to collect as-built information.

The benefits of using MDS go far beyond basic CADD tools because intelligent design "modules" allows owners to explicitly capture design criterion, insuring project quality. By utilizing COTS, owners can focus their efforts on improving the design modules, specifications and details so designers can spend more time evaluating alternatives while consistently applying owner and industry standards. People involved in construction, operations and management, maintenance, etc., can also provide lessons learned feedback to improve the design modules and avoid repetitive mistakes. Other immediate benefits include improved multi-disciplinary communication and coordination, robust modeling and engineering visualization capabilities, shortened project delivery time, capture of corporate knowledge, and a better end product. This benefit supports the US Army Corps' Vision in the areas of Revolutionizing Effectiveness, Improving Performance, and Increasing Customer Satisfaction (USACE 1998).

7 Conclusion

The current MDS implementation must be modified to meet future requirements as interests expand beyond the original scope of the MDS project. The MDS 3.0 Framework will provide an information infrastructure foundation to transition MDS into the next century. The framework will exploit standard efforts in the software industry and domain relevant efforts such as IAI and the National CADD Standard. Working with industry partners, the framework will utilize plug and play capabilities for sophisticated engineering analysis activities while providing minimum domain specific capabilities. The MDS 3.0 Framework will focus on the information modeling requirements and manage the model independent of specific applications. The model will become a life cycle corporate asset that is reusable and adaptable.

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248 AN INTERNET-BASED DISTRIBUTED BUILDING DESIGN SERVICE FRAMEWORK

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Abstract

This paper describes a distributed service architecture that enables the delivery of building design services over the Internet. With this architecture, it is possible to rapidly deploy various services, both new and legacy applications, that can be easily accessed via the Internet. As examples of services, the prototype implements a top-level brokering service, a project manager service with a companion CAD package service, and a set of disabled building code analysis services.

Keywords: automation, distributed object environment, World-Wide Web (WWW), Computer-Aided Design (CAD), Industry Foundation Classes (IFC)

1 Introduction

Traditional CAD systems are monolithic in that all functions or "services" are bundled in a software package. With the maturation of information and communication technologies, the concept that distributed CAD services are delivered over the Internet, Internet-based Computer-Aided Design, is becoming a reality. Regli (1997) outlined the technologies that are now readily available to make the network-enabled CAD environment possible. Specifically, the technologies include a standard product model and a distributed object environment that allows for the development and transfer of a design based on the standard product model.

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This paper describes a prototype implemented to illustrate a framework that provides building design services over the Internet. The framework provides a means to distribute design services in a modular and systematic way. With this infrastructure, users have the ability to select appropriate design services (as opposed to having to use a large monolithic design tool) and can easily replace a service if a superior service becomes available without having to recompile the existing services being used. With the standardization of the communication protocol and the exchange of product model data, integration of legacy applications as well as deployment of new design packages becomes a straightforward task. As examples of services, the prototype implements a top-level brokering service, project manager service with a companion CAD package service, and a set of disabled building code analysis services.

2 Infrastructure of the framework

Fig. 1 shows the conceptual network-enabled framework for a distributed service. In this framework, each individual service adheres to a two- or three-tiered architecture. The first mandatory tier, a communication protocol interface, gives the application services a common means to send and receive data over the Internet. The optional middle tier, the common product model interface, is a standard protocol that describes the design data for a design service. The mandatory third tier is the core of the service—if the service is a design service, it extracts the appropriate information of the building design through the common product model interface and either modifies the design data or generates a report based on the analysis of the data.

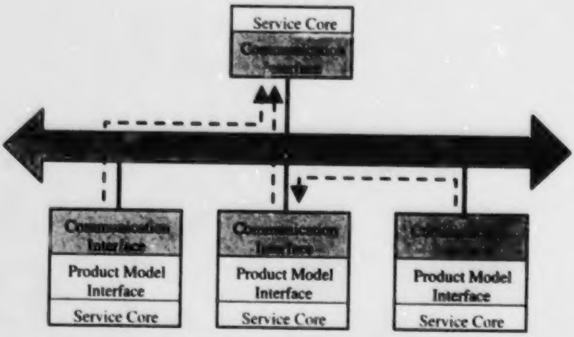

Fig. 1: A conceptual diagram of the distributed service architecture

As shown in Fig. 1, a non-design service does not need the product model interface that is present in the design services. An application package can register its services (the dashed line in Fig. 1) with a brokering service and advertise its services in the infrastructure. Another service will query the brokering service for the existence of services in the distributed service architecture. Note that a design service can also act as a brokering service. The registration and query service is based on a predetermined constraint language. In the following, the design of the multi-tiered architecture is examined in detail.

2.1 The Mandatory communication protocol interface

Methods that define the communication protocol interface that are made publicly available by a service is illustrated in Fig. 2. Following the object-oriented paradigm, the "exposed" methods are the points of entry into a service, but the actual implementation of these methods is dependent on the individual broker or service.

```
module DistributedServiceArchitecture
{
  interface Service;

  typedef  sequence<boolean>       BooleanArray;
  typedef  sequence<Service>       ServiceArray;
  typedef  sequence<string>        StringArray;

  interface Service
  {
    void         registerService(in Service service);
    Service      getRegisteredService(in string serviceId, in string serviceType);
    ServiceArray getRegisteredServices();

    string       getServiceId();
    string       getServiceType();
    void         putServiceType(in string serviceType);
    void         putServiceId(in string serviceId);

    void         execute (in Service callingService, in string sessionId, in string command);
    boolean      getStatus(in Service callingService, in string sessionId);
    void         notifyService(in Service calledService, in string sessionId, in StringArray data);

    void         clear(in Service callingService, in string sessionId);
    boolean      containsKey(in Service callingService, in string sessionId, in string key);
    BooleanArray containsKeys(in Service callingService, in string sessionId, in StringArray keys);
    string       get(in Service callingService, in string sessionId, in string key);
    StringArray  gets(in Service callingService, in string sessionId, in StringArray keys);
    void         put(in Service callingService, in string sessionId, in string key, in string data);
    void         puts(in Service callingService, in string sessionId, in StringArray keys, in StringArray data
    void         remove(in Service callingService, in string sessionId, in string key);
    void         removes(in Service callingService, in string sessionId, in StringArray keys);

  };
};
```

Fig. 2: The communication protocol interface

In the simple prototype implementation, the brokering portion of the interface defines two methods, `registerService()` and `getRegisteredService()`. For the purposes of the prototype, this simple interface is sufficient to illustrate the minimum specification of a broker. In addition, one service can execute a command in another service using the `execute()` method, and the called service can then notify the calling service when the execution is complete using the `notifyService()` method.

The interface for communication of design data is also very simple with `puts()` and `gets()` being the most important methods. The `puts()` method sends the product model to the service with two arguments, a string identifying the name of the model and a stream of data that defines the model. The `gets()` method returns a model with the name identified by the single string argument.

In a previous prototype, the brokering methods were contained in a separate brokering object than the service object (Han 1999). However, allowing services to register and query other services provides the most flexibility and better distributed functionality. Following the distributed service paradigm, services may be distributed as processes of one CPU, processes of a multi-processor system, or among workstations within a cluster. When services register with a higher-level service, this higher-level service can execute commands of the registered services as threads. With this small set of methods, the communication protocol layer is fully functional and can be utilized by an application that operates within the distributed network-based environment.

2.2 The optional product model interface for design services

The availability of multiple design services suggests a mapping of each service's design data representation to a common model. Without this *lingua franca*, a process that needs to use a specific service would need to have a mapping of its representation of the design data to the service's design data representation, and the need to use a new service would require additional mapping.

With the multi-tiered service architecture illustrated in Fig. 1, the product model interface has been deliberately decoupled from the communication protocol interface. Using a distributed object paradigm, it would have been possible to expose the objects or building components of a common product model in the communication protocol interface, thus combining the communication protocol and product model layers. However, if the objects (and their attributes and relationships) are made public at the communication protocol level, as the product model evolves, the communication protocol must also evolve to take into account the product model evolution. By decoupling the two layers, it is up to the individual service whether the product model interface needs to be modified to accommodate the product model evolution. Finally, since some services do not require the product model layer, separating it from the communication layer allows for a smaller communication protocol.

As previously noted, the `puts()` and `gets()` methods of the communications protocol interface take as input and output a stream of design data as strings. In decoupling the two layers and keeping the infrastructure general, the trade-off comes in the efficiency of sending the design data. Although there are no restrictions on how the string array is imposed by the infrastructure itself, in the prototype, the string array is a description of the model in EXPRESS format.

2.3 The mandatory service core

There is a distinction between the functionality of a non-design and a design service core. For a non-design service, the core layer will simply process queries and the registration of services. Since there is no product model associated with a non-design service, no transformation or modification of a product model is required.

Any design service needs to extract a view or a diagram from the product model (Clancy 1985). The transformation from the product model to a view or a diagram is unique to the application. The core of the design service needs to map the common product model data to its own design data representation. If part of the task of the design service is to modify the product model that has been deposited into its repository, the service must then perform a reverse mapping from its own design data representation back to the common product model to update the model. Otherwise, the service simply generates a report.

3 The distributed service architecture prototype

This section describes the technologies used to implement the distributed service architecture for building design services as illustrated in Fig. 3. The service communication protocol layer is implemented using CORBA. CORBA provides a high-level distributed object paradigm that is well-suited to implement a network-based distributed service architecture. A combination of a simple, flexible generic product model and the geometric properties of the International Alliance of Interoperability (IAI) Industry Foundation Classes (IFC) (*Industry* 1997) is employed as the common product model for the design services.

Java is employed as the programming language to implement most parts of the distributed service architecture. Java's well-designed object-oriented structure and platform independence were the influencing factors in using it as the implementing programming language. The wide proliferation of the Internet can be attributed to the ease of World-Wide Web access, so taking advantage of this environment was appropriate. When interaction was needed within the Web browser environment, Java applets could be seamlessly integrated into the Java-written distributed architecture. The CAD service employs a Java applet to create browser-based interfaces.

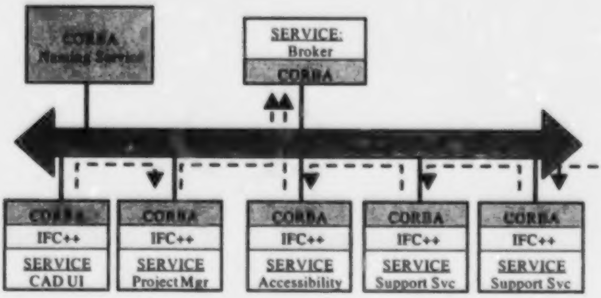

Fig. 3: A distributed service architecture implementation

3.1 The common distributed object environment

The communication protocol interface shown in Fig. 2 is the Interface Definition Language (IDL) file used to generate the CORBA-related Java source code. Though applications access objects and their methods defined in the IDL file in a distributed object environment across the Internet, from the application's point of view, these objects and methods are treated as local entities. This concept underlines the power of the CORBA paradigm.

One feature of CORBA is the Naming Service which allows distributed objects or applications to register and locate other distributed objects or applications at a common location by name (Vogel and Duddy 1997). The order in which the various distributed applications are launched is critical: The Naming Service must be launched first. For the prototype, a top-level broker service called "SimpleTrader" is the first process that registers with the Naming Service since the design services will register with the broker. The design services must be launched before their respective clients (the CAD service is a client to the project manager service). One responsibility of the project manager service to query the broker for the availability of design services. If a design service has not been launched (and therefore has not registered with the broker), when the broker is queried by the project manager service for that design service, the broker will simply inform the project manager service that the requested design service is not available.

3.2 The common building product model for design services

The communication protocol interface specifies methods for sending and retrieving a building model from a service without the interface having any knowledge about the semantics of the building model. However, understanding the semantics of the building model is the responsibility of the product model interface. In the prototype, a generic and flexible product model is used. A generic building component, `GenericComponent`, has only an identification string and three fields defining its form, function, and behavior. The form is described using the IAI IFC geometric representation scheme. Fig. 4 illustrates the product model hierarchy.

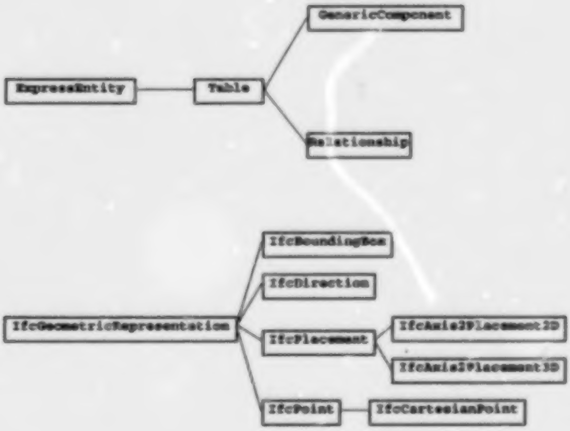

Fig. 4: The common product model hierarchy

The product model interface constructs an internal representation of the design data from the data stream. The only restriction mandated by the common product model interface is that the core of the design service accesses the building components in the repository by the name of the model and the name of the building component.

4 The Services

4.1 The top-level broker: a non-design service

As previously noted, a non-design service does not require the common product model interface, and the top-level broker is an example of a non-design service (see Fig. 3). The top-level broker registers with the CORBA Naming Service and waits for other services (in this case, the design services) to register with the top-level broker. When an application queries the top-level broker about the existence of a particular registered service, the top-level broker will reply by returning the applicable service object to the querying application. Once the querying application receives the applicable service object, the querying application is able to interact with that applicable service object by sending the appropriate design data.

4.2 The project manager service with a client CAD service

The project manager is a very simple service to illustrate the functionality of the communication protocol and product model interface. Since the main function of the project manager service is to act as a repository of building models, the service core layer does not perform any design data extraction and analysis from the building model that resides in the product model interface. The only other function the project manager service has is to process queries from the registered client CAD service by first passing the queries to the broker and then transferring the service object that the broker has returned back to the CAD package. In an enterprise environment, instead of simply acting as a pass-through mechanism, the project manager service would authenticate a CAD service when the CAD service registers with the project manager. The project manager would also act as a security agent that would filter the CAD package's service request depending on the constraints of the specific project.

The client CAD service, a combination of a Java Applet and a Virtual Reality Modeling Language (VRML) ("Information" 1997) interface, is launched when its Web page is accessed. Fig. 5 depicts the details of the CAD package architecture. The applet first retrieves the project manager service object from the CORBA Naming Service and registers with the project manager. It can then send requests to the project manager using the `gets()` and `puts()` exposed methods. The third tier or service core of the client CAD package includes the UI. The Java applet handles the textual UI, and the applet communicates with the VRML graphical UI using the VRML External Authoring Interface (EAI) (Marrin 1997). The various aforementioned Web browser-associated technologies allow rapid prototyping of the client CAD package.

The CAD package can retrieve building models either from the project manager service repository or from a static local model file, which is in EXPRESS file format. The retrieved model can be viewed, modified, and saved back to the project manager repository. In addition, the CAD package queries the project manager for the available design applications that have been registered, and it can send the model that is currently being developed to the design applications.

4.3 The Disabled Access Code Analysis Application Services

The disabled access code analysis application is an example of a set of hierarchically structured design services. By structuring an application as a set of service modules, the application can be distributed across a network of processors or a cluster of workstations. If the service modules are initialized on the same workstation, it is the responsibility of the workstation's operating system to distribute the modules as separate processes in a single-processor machine or among the processors of a multi-processor machine. Currently, to distribute service modules of a particular application within a cluster environment, the service modules have to be manually initialized on separate workstations. Following the distributed object paradigm of location transparency, a service that registers other services does not know whether the registering service resides on the same workstation or on a different workstation in the cluster.

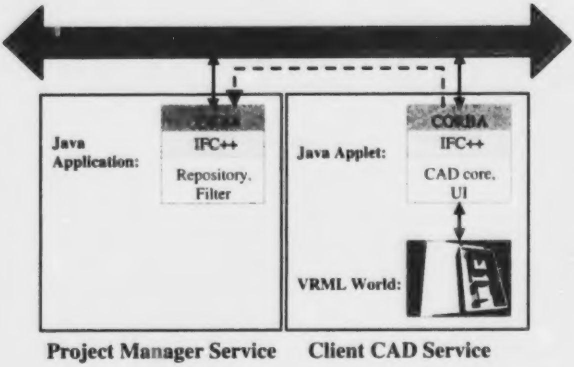

Fig. 5: The program manager service and the client CAD service

As shown in **Fig. 6**, the top-level service of the disabled access code analysis application registers with the top-level broker service described in Section 4.1. Two service modules of the disabled access application in turn register with the top-level disabled access service. One of these modules is a path-planning service that analyzes a design for the existence of an accessible path using motion planning techniques described by Latombe (1991) and Han (1999). The other module initiates a chain of modules that the disabled accessibility application uses to decompose the design in a hierarchical manner. The chain consists of modules that decompose the design on the project level, site level, building level, story level, space level, and finally on a cell or sub-space level. This hierarchy mirrors the implemented product model hierarchy.

The top-level design service receives the design data from another application (such as the previously described CAD service). The top-level design service acts as a broker for the path-planning service since it does not actually send design data to it. The top-level design service, does however, send design data through the chain of service modules. Each of these modules uses the path-planning service by first querying the top-level design service for the path-planning service object. Once the particular service module in the chain receives the pertinent path-planning data, it further decomposes the design model by sending parts of the design to the next module in the chain.

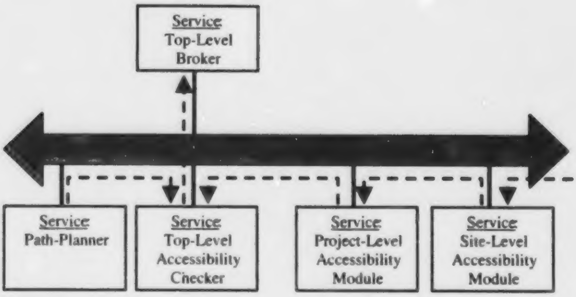

Fig. 6: The accessibility analysis service and the generated report

5 Discussion

This paper has described a distributed service architecture that allows design services to be incorporated into a modular network-enabled infrastructure. By providing a modular infrastructure, services can be added or updated without re-compilation or re-initialization of existing services. In addition, by allowing portions of a service to be further modularized and to register with a parent service, separate tasks of an application can be distributed over the network. Other building-design-related services than the ones described can be implemented and linked to the network infrastructure. For example, if a building component inventory service is implemented, a designer could query such a service for the availability and pricing of a specific component such as a fixture, an appliance, etc.

The infrastructure is contingent on the interfaces for the communication protocol and the common product model that is required for design services. Standardizing a communication protocol and decoupling it from the product model interface has its advantages and drawbacks. The major advantage is that the communication protocol interface does not depend on changes (updates and evolution) of the product model since the stream of design data is object-independent; it is the responsibility of the product model protocol to parse the design data stream. The major disadvantage is the inefficiency of the transmission of the design data from service to service.

Finally, the distributed service architecture prototype described in this paper does not address issues of security raised by Regli (1997) and others (for example, see Wiederhold et al. (1997) and version control (Krishnamurthy 1996)). Security issues could be addressed in the communication protocol interface and the project manager service while version control could be incorporated in the common product model interface.

6 Acknowledgments

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249 INTEGRATION OF PARAMETRIC GEOMETRIC MODELING AND CONSTRUCTION SIMULATION

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Abstract

In early ages 'Designing' of a building could not be differentiated from 'building' it, since the Master Builder was also the designer. With the increased complexity of design, this arrangement changed. Currently designing a building and constructing it are two different tasks. The description of design is done using drawings, whether in 2 or 3 dimensions, while construction operations is usually described by means of construction schedules. Three-dimensional details of building assemblies are often used for describing the design details. If we can describe the building details parametrically with construction operations only, then we can save time in developing assembly details and improve constructability. This paper describes a new approach to store design description of assembly details as intelligent objects. Each of these objects represents a building assembly. These assemblies are linked to a database of networks, that generically describe how the assemblies are built/drawn (i.e. the components used and the geometric/construction operations). A prototype system EASYBUILD is introduced.

Keywords: Architecture, engineering, construction, simulation, geometric, modeling parametric.

1 Introduction

Computer aided design and drafting (CADD) has been a viable tool for the Architecture Engineering and Construction (AEC) industry. A major drawback of today's automations in building design is that design tools are defined in alienation from the construction stage (De Vries 1995). CADD systems are developed without

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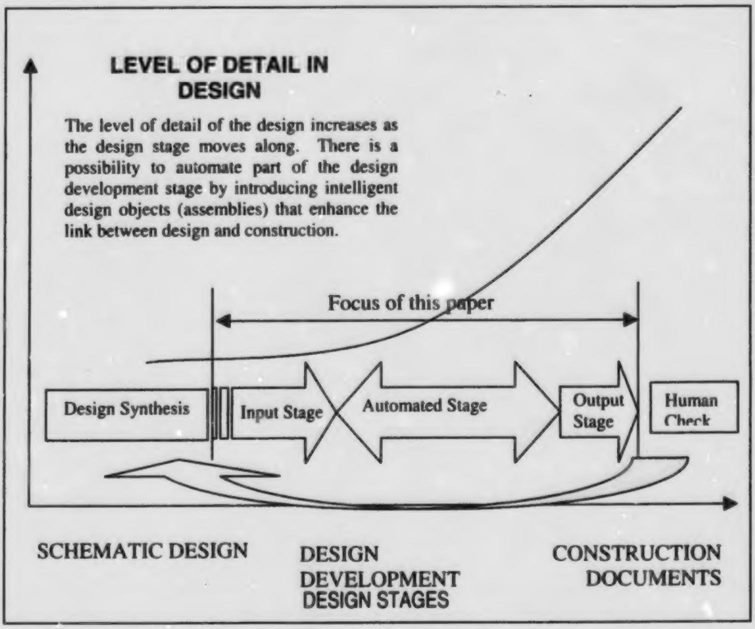
taking available construction operations into account. Increased computer capabilities lead to increased design possibilities that are difficult to construct.

In the building delivery cycle of today there are several gaps between design and construction. Part of the reason for this is due to the separation of the design description methods and the construction description methods. Construction is usually described by the construction schedule. Methods like CPM, PERT or activity cycle diagrams for cycle/repetitive processes can be used to describe construction processes. The design of the building is usually described by a drawing, made up of geometric primitives that represent physical construction objects or abstractions of these objects. There are several stages in the building design process in order to reach from a basic drawing description of the building to the construction schedule stage, as shown in Figure 1. The design synthesis stage is where the design concept is formulated. After the design concept is formulated, an automation stage can develop the design concept and provide details for that design. This is the focus of this paper. Checking from the designer can refine the detailed design or iterate through the design cycle again.



The level of detail of the design increases as the design stage moves along. There is a possibility to automate part of the design development stage by introducing intelligent design objects (assemblies) that enhance the link between design and construction.

Fig. 1: The design/construction process and the possible integration stage

We can integrate the design geometric modeling operations and the construction operations for building assemblies. Each of the geometric representations of the assemblies can become a dynamic object that is linked to a description/schedule of how it is built. Each time the assembly representation is used in a design it builds itself virtually on a computer by drawing its components. The sequence in which the components are drawn is described by a set of parametric operations. Components used can be three dimensional geometric objects. The construction sequence can then generate a realistic 3D model of the building for different assembly shapes and component sizes. This requires us to describe the sequence of construction and the geometric modeling operations that are required to generate the model in an integrated way. To accomplish this we firstly need a building product model that breaks down the building into various objects and relationships. This has been discussed in earlier in the literature (Nassar 1998; Eastman and Siabiris 1995). Secondly, in order to be able to reuse the objects the geometric modeling and construction operation must be described in a parametric way that gets evaluated for each specific design situation.

The developed prototype system, EASYBUILD allows the designer to parametrically describe how certain assemblies are built using a simulation network structure. This network is evaluated for each specific design to produce the final detail of the building.

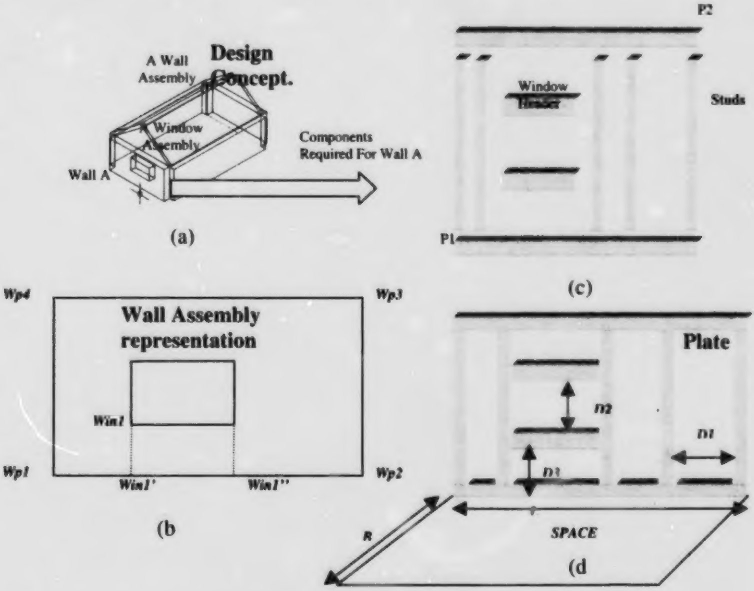


Fig. 2: The example stud wall and the parametric variables

Parametric modeling techniques are described in section 2. Section 3 introduces simulation networks as a construction process modeling technique. Finally in section 4, we describe how we can integrate the two techniques and a computer prototype system EASYBUILD is described.

2 Parametric modeling

There are two main issues in geometric modeling, first the geometric representations of the components, and second the relationships between these components. In addressing the problems of design, the relationship between the components is more problematic (Hall. 1991).

To specify the geometric relationships between the components in a simple wall assembly so that these relationships get evaluated for each particular design, several parametric modeling techniques can be used. The goal is to describe and store the assembly parametrically so that each time the assembly is used in a design it is drawn automatically. In Figure two a simple design concept (a), a geometric representation for two of the assemblies (window and wall) used in that concept, (b) and the components required to build the assemblies (c) are shown. A description of the geometry of the detailed assembly (d), in a parametric form is required, so that the parametric description can be reused for other assemblies. In this case the detail is for a wooden stud wall. Below we will describe two of the parametric modeling techniques, simultaneous equations and constructive specification. A complete description of parametric modeling techniques can be found in (Roller 1991; Cugini at al. 1998; Lee and Andrews 1985)

2.1 Simultaneous equations

The simultaneous equations method is based on translating all dimensional constraints into equations, where the unknowns are the coordinates of the characterized points of the geometric model. In the example the characterized points are shown. Subsequently a system of equations is defined which can be solved by an iterative numerical method. For example the linear distance *D* between the 2 points $Wp1(x1, y1, z1)$ of the wall assembly and $P1(x2, y2, z2)$ of the plate component, can be translated into the constraint equation,

$$F = (x1-x2)^2+(y1-y2)^2+(z1-z2)^2-D^2 = 0 \tag{1}$$

This approach can continue until we have fully constrained our model. Constraint equations are in general non-linear and are usually resolved using the Newton-Raphson iterative Method (Lee and Andrews 1985). This approach usually requires skilled user intervention to condition and solve equation systems.

2.2 Constructive specification

This approach utilized the construction sequence of the design. Different parametric design methods based on this approach have been devised. One of the approaches (Roller 1991) introduces three classes of geometry, FIX, VARIABLE and

FLEXIBLE. Geometric elements that are to have fixed dimensions are constructed in FIX mode. For elements that require variable dimension parameters (length, radius, angle) VARIABLE is used. Sometimes the length of an element is not explicitly known but has to be fit between existing points (e.g. the length of the window header in Figure 2). FLEXIBLE mode is used for this type of geometry.

In order to relieve the user from explicitly specifying all of the implicit constraints a set of constructive operations can be devised, e.g. in 2 dimensional geometry, POINT_to_POINT fixes one shape to a certain point on another, LINE_HORIZONTAL forces an edge of a shape to be horizontal. EASYBUILD is a prototype system that allows constructive specification operations for building assembly. In EASYBUILD these operations act on 3D components in the assembly. A set of constructive operations is defined in EASYBUILD. A PLACE operation for example positions a component relative to 2 characterized points and a rotation, (relative to the assembly geometric representation coordinate system).

In Figure 2 for example, in order to specify that we need to place a plate at the lower left corner of a wall,

PLACE (wall, plate, *wp1*, *p1*, 0)

Since all of the wall assembly geometric representations have a characterized point *wp1*, the actual coordinates can be evaluated for all of the walls with wooden stud construction. Currently EASYBUILD utilizes a set of constructive operations; CUT, PLACEARRAY, REMOVE, SHAPE, ASSEMBLE. Future development will introduce other operations. We now need to introduce construction simulation as a process modeling technique, which can help us to model these constructive operations.

3 Construction simulation

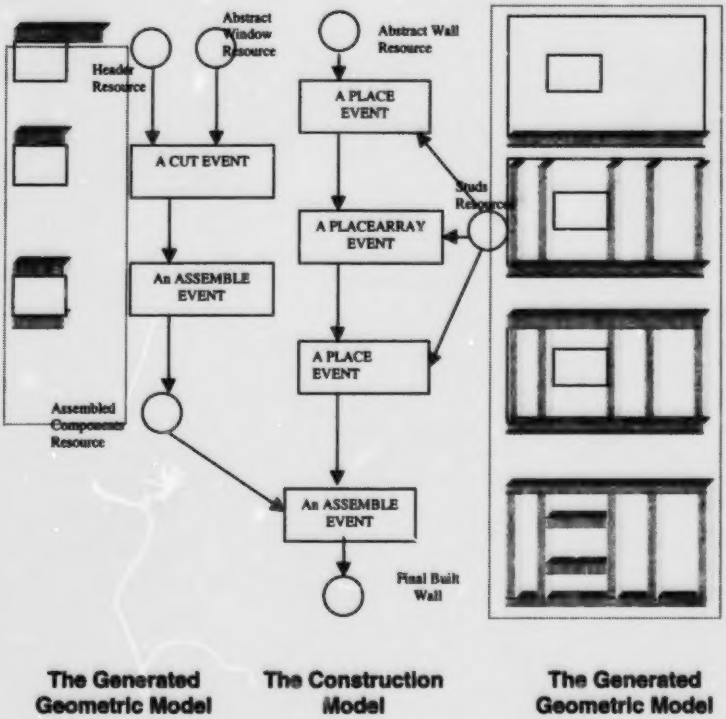
Several simulation techniques focus on the construction industry and attempt to describe a construction sequence. A detailed description of simulations in construction can be found in Martinez (Martinez 1996). Simulation models allow a concise representation of repetitive activities and explicit formulation of resource flows (Senior and Halpin 1998).

CYCLONE (Senior and Halpin 1998) is probably the most common known of construction simulation techniques. Stroboscope (Martinez 1996) is another simulation tool based on CYCLONE that provides many additional utilities. In stroboscope active states are referred to as COMBIs and NORMALs and units are held in QUEUES. A description of simulation models can be found in (Martinez et al. 1994). Next we will describe how the parametric constructive operations can be integrated with simulation networks.

4 Integrated approach

The proposed approach allows designers to specify the construction sequence of the assemblies generically using simulation networks. These events (COMBIs and

NORMALs) in these simulation networks are made up of constructive geometric operations.

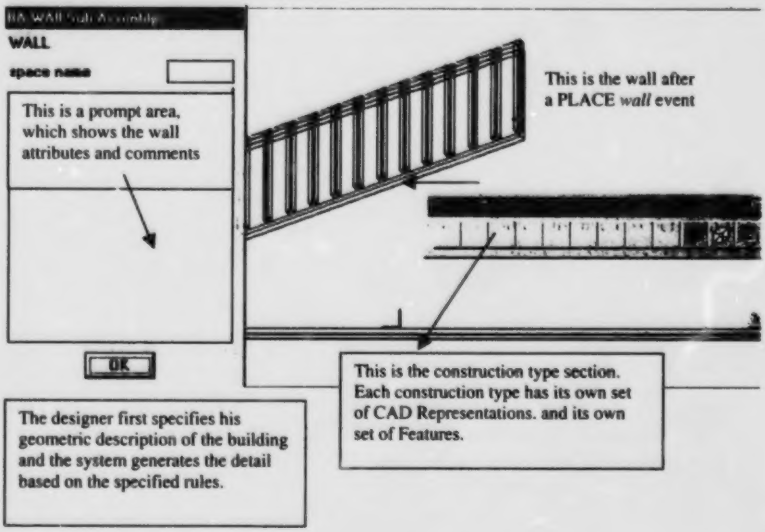


The Generated Geometric Model **The Construction Model** **The Generated Geometric Model**

Fig. 3: A simulation network showing a cycle for one wall assembly

The components that make up the assembly (e.g. the studs, headers and plates) are considered resources. Resources are objects that the various events in the network use to perform their tasks. Also, the assembly itself is modeled as a characterized resource type. Characterized resource types are a special kind of resource that can have particular attributes and specific values for each individual resource entity. In stroboscope a queue of a certain type can carry resources of its subtype. Each instance of the assembly resource is modeled as a subtype. So for instance the wall assemblies are considered a resource type and are assigned to a separate queue. The queue is filled with a set of subtypes resembling the different walls in the design concept. Each of those subtypes carries with it the geometric information (the parameters to the operations).

In the example shown in Figure 3, the wall and window are modeled as characterized resources. These resources are called abstract characterized resources because they do not actually get used but only their attributes are used to perform the geometric operations. The constructive operations are defined as the events that act on the resources. The wall resource has as its attributes the characterized points. The operations in the events are defined parametrically, i.e. they specify the characterized points of the assemblies as variables. These points are specific for each wall. As the wall resource moves through the network the operations act on it to construct the 3 dimensional model.



This is the wall after a PLACE *wall* event

This is a prompt area, which shows the wall attributes and comments

This is the construction type section. Each construction type has its own set of CAD Representations. and its own set of Features.

The designer first specifies his geometric description of the building and the system generates the detail based on the specified rules.

Fig. 4: The prototype system, EASYBUILD

5 Conclusions

In this paper a new approach for integrating construction and geometric modeling processes of buildings was described. This approach allows the designer to generically describe how certain assemblies using a simulation network structure. This network is evaluated for each specific design to produce the final detail of the building. A prototype system EASYBUILD (Figure 4) is underway. The EASYBUILD system allows the user to define a construction sequence. The user also can then specify the design of the building in terms of the various building assemblies. By reasoning with the specific design geometry the predefined simulation networks are set up with the proper variables and resources. Running through these networks produces a 3D model of the building assembly details in a commercial CADD package (AutoCad).

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250 A SEMANTICALLY RICH REFERENCE MODEL FOR BUILDING DESIGN

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Much effort has been expended by software developers attempting to build databases suitable for use by those working within the construction industry. Various models from the original RATAS relational database model through to sophisticated process models have been proposed, developed and evaluated. It is probably fair to say that these research efforts have only recently begun to effect the practices of professional construction engineers. This, in part, is due to the need for more sophisticated systems. This paper describes a database that is usable throughout the design and construction processes in the construction industry. The method uses the well-established idea of generic components that can be combined to create a large scale artefact. The novelty of the approach described herein allows the components to embody facts and rules that allow design knowledge to be modelled, captured and retrieved. The facts and rules encapsulate not only the interactions of the various products but also the processes involved in their use. In effect, the atomic primitive elements (both components and rules) can be combined to create complex elements which are semantically rich. The basic ideas and fundamental philosophy of this approach have been described elsewhere. This paper is devoted to describing the detailed implementation of this approach. The content is technical and thorough; it describes how a passive relational database management system, Oracle, has been used to create a new metadata structure for the creation, control and management of the components - both simple and complex. In effect, the relational database becomes active. Thus, the database reacts to design decisions by firing rules which then govern the interaction of the components. The paper presents a detailed description of the underlying architecture and the data model which has been developed. The paper is interesting not only to construction engineers but also to software designers in that it shows how existing database models can be extended by using their predefined data types to create new, and more complex, ones. While this is an old, well-established trick, this application to a real-world problem is a good test of its viability. Finally, a brief review puts this particular approach into the context of the other myriad attempts to create product and process reference models with an evaluation of its strengths and weaknesses.

Keywords: Active database, Component model, Design database, Product model, rules

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1 Introduction

The design, development, and evaluation of reference models has become a popular activity amongst researchers working in the area of construction information systems. Product models, process models, standardisation efforts, and system architectures - all of these have become standard fare. One might cite the work of Wix and Bloomfield (1997) and Wix and Liebich (1997) in the area of standards, Brown *et al* (1996), Hazelhurst *et al* (1997), Björk (1997) and a host of others in proposing various system architectures and paradigms. This paper is no different. Yet, this somewhat flippant exposition should not hide the usefulness and necessity of all these efforts. On the one hand, the realisation that this application domain is one of the most difficult to computerise is now well established. Construction projects combine a depth of complexity, a massive volume of data - and high volatile data at that - and a fragmented organisation framework that have made it difficult to build truly useful systems. Whereas self-contained systems have been successful in their own limited domains, CAD in particular being such an example, the unification and sharing of data across systems has yet to occur. On the other hand, there has been a slow but growing realisation that the computer and software tools at our disposal have been inadequate to the task. In this regard the application domain has acted as a spur to the systems developers to come up with the tools that can do the job. If the linkage is not direct one might posit that the growth of object-oriented systems, with their emphasis on objects - that is to say, encapsulated abstract data types - has come to the aid of construction system developers who have tried to reconcile the differing approached characterised by the product modellers and the process modellers.

This paper takes forward both the ideas behind construction reference models and those behind current thinking on databases. Thus as an application this paper describes a reference model that is active and thus semantically rich. Whereas its contribution to database theory is to show how triggers and actions can be used to create an active database. While this latter achievement is rather clumsily engineered, the ideas should prompt database designers to think of better ways to achieve the desired effects.

A number of papers have already been published that are based on the underlying research for this paper. This paper takes a small step into the build of the proposed system and defines its structure, inspiration and an overall decomposition of the system that is build based on the research.

This paper provides an overview of the model proposed and the scope of the research undertaken to develop the active component model. It then shows an overall functional decomposition of the model. The paper is based upon an earlier one (O'Brien and Baig, 1998) which laid down some of the guiding pronciples behind this work. Much of the justification for this work has been previously published; this paper therefore describes some of the more technical aspects of the work. However, a full description of the model and the system that has been developed based on the model is outside the scope of this paper.

1.1 Overview

The proposed model illustrates how components are structured, built and managed, how semantic rules about the design components are incorporated into a database and how these rules can be used to elicit active database behaviour. The model defined here relates to the construction of a building, the principles underlining the model can however be applied to any database that is used for design purposes. The model is not a full-scale design database; a prototype system has been developed to create a scenario for developing semantically rich components that can be used to elicit active database behaviour.

1.2 Design overview and requirements

The aim of this section is to provide the overview and requirements document from which the first cut of the ERD can be developed. Concepts mentioned in this section are discussed in details in the thesis by Baig to be published in the near future. A systematic approach is developed that allows the creation of components, which hold not only their properties but also the rules that effect their behaviour. These components are then used to build a semantically rich design model. (From hence fourth a design will refer to building construction design unless otherwise stated.). In order to achieve this the following facilities need to be developed.

- A way of defining atomic components,
- a process of assigning properties and rules to the components,
- a way of associating lower level components to build higher level components,
- methods of defining the general environment within which the components are placed and interact, such as site conditions, space and time, and
- method for hold design history and permitting changes arising from future eventualities or pre timed events.

A component is either an object or a construct it has factual properties and forms a part of the physical world. A construct is an abstract component that also has properties or features. The factual features can be inherent to a component or interdependent between many components. Fore example the features of an office building and all its parts can be considered to be internal while the relationship between the office and the workers is an interdependent relationship.

The features themselves can be internal or external. The internal features are independent of any outside influence where the facts are applicable to the component and only the component. External features are dependent on the component interaction with the outside world. Fore example the stress tolerance is an internal feature of a construction beam while its inability to rest directly on a wall is an external feature because it refers to the components interaction with the outside world. The external features can be objective or subjective. Subject features refer to feelings, opinions and intuition. To say that a straw roof 'feels warmer' on country cottage than a roof made from black slate is a subjective feature. External features are rules that apply to a particular component they determine its behaviour and its relationship with other components and the environment within which it resides. Rules are based on the internal features of components. They can be constant or dynamic. Dynamic rules vary and adapt according to their interaction with other components. The fact that the energy requirements from a hot water tank to heat the water to 30°c will vary according to the external temperature of the tank means that the rules must consider dynamic factors in their evaluation before carrying out the appropriate action.

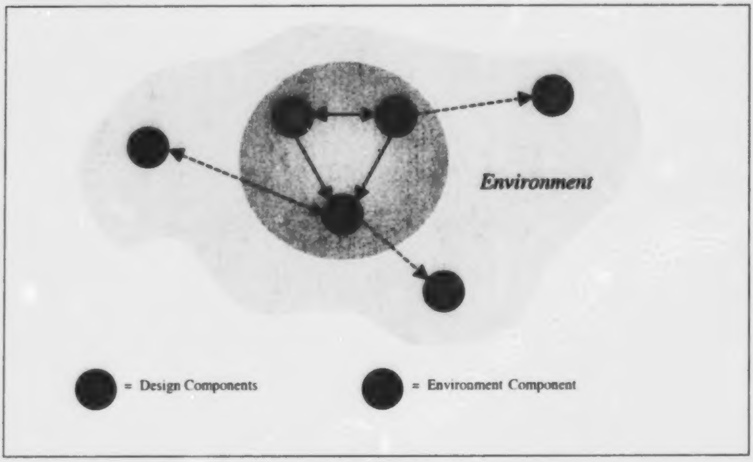


Fig. 1: General design concept using components

A component will change either due to some interaction with other components or with time, thereafter its properties will change accordingly. This refers to the state of the component, hence, the state of a component is the factual data and state changes can be bought about by a change in the rules. The firing of legitimate rules can create a state change. For example a door has different states of openness that can be represented by the function for the angle between the wall and door. The function can take values from 1-180°, other values are not allowed because the relationship rules of the door and wall, hence, any other state of openness is not permitted. The state change can be easily controlled and measured but in some cases a state change that would normally not be allowed may be required. In this case the properties of the components need to change to accommodate the fulfilment of the new state, however, the percussion for 'impossibility states' must exist. In the above example it is impossible for a door to open beyond 360°. The impossible state could also be governed by the rules of the environment. The process of a state change is considered as an event, multiple events or an operation. The firing of events and operations lead to 'indirect' state and/or property change to other components, and some that may not be obviously related. A class is the collection of all properties that make up the component. A component is a member of a class if it has properties, which define a class. A component 'kind' is determined by a set of properties. Fore example a house is a member of the class residential duelling and it also belongs to a kind of accommodation. Classification is a way of grouping the external features into equivalent classes but varying degree of granularity. Within the process of classification individual members are related to some common set and set are related to sub-sets.

New component created by combining existing components has rules that belong to it self even though its properties are based on the properties of the existing components. The environment also influences the emergence of rule within the new component which means that design can not be considered without considering its environment (Ackoff, 1979). An overall design is a collection of the necessary components, an environment that acts upon the design and is acted upon by the design and a method of organising and relating the design.

As shown in Figure 1. The overall design also behaves like a complex component that has internal and external features and states. The word overall design is used loosely as it can itself form a larger design. In this case it is referred to as a sub-design or even a sub-components, the higher level design is referred to as a super-design or super-component in relation to its sub-components. The 'whole design' can therefore not be a sub-component of any thing. A sub and super design introduces the concept of levels. Unlike a hierarchy the higher level design is not linked to a lower level design they are all designs in themselves. The higher level design is made from lower level design and its components. The lowest level design is called an atomic design. Any particular level does not act on its parts. The elements used to link components are regarded, as components them selves and will be referred to as linking components (links), which also have internal and external features. The linking components can be those that physically join two components and generic components that associate components these will be referred to as 'specific fasteners' and 'generic fasteners'. Operations such as moving, close, new may be regarded as generic fasteners. In object oriented terminology these may be referred to as polymorphic objects. The use of a link will produce a new component. This may be of a components-link-component relationship or component-link relationship the latter will normally produce a variation to the participating component. In Figure 2 component 'A-fixed to-B' consists of Component A, Component B and a 'Fixed to' link component. The type of link will determine the result and hence the nature of the new component

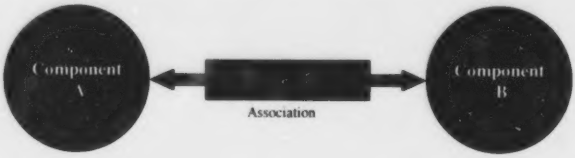


Fig. 2: Component A-fixed to-B

1.3 Rules in the active component model

The rules within the active component model are ECA production type rules and are based on the component facts as discussed in the thesis to be pubised by Baig. The events, conditions, and actions are explicitly declared and are encapsulated into the rule. In addition rules can have attributes and carry other context information, such as coupling mode. Separation of the events, conditions and actions and the use of declarative rule management on the RDBMS have several advantages these are:

1. Provides a unique interpretation of the rule,
2. permits the coupling of rules with triggering transaction in several ways: event-condition, condition-action, and event-condition-action grouping is possible,
3. knowledge of the action portion of the rule as well as the event portion of the rule can be used for optimising the rule,
4. perform transformations by pushing computations from action to condition and from condition to event without changing the execution semantics,
5. two or more rules can be combined into a larger rule,
6. rules can be related to application areas, hence, grouped by context, thus reducing the scope of searches. It is also possible to create sub classes of rules that have their own attributes, and
7. rules can be modified, inserted and deleted in the same way as other data in the database. They are subject to the same transaction semantics as other data objects, such as concurrency controls, therefore rule that is being fired by one transaction cannot be modified, deleted or disabled by another.

1.4 Other systems and product models

This section provides a brief outline of three related systems that relate to the design for the active component model proposed in the underlying research. These are General AEC Reference Model (GRAM), The AEC building model and the RATAS model. These are all rather venerable predecessors but they have effectively established the various developmental lines of research.

1.4.1 GRAM

GRAM is a method of defining a product model and its decomposition for the purposes of design. Within GRAM a product is represented as a PDU, Product definition Unit (Gielingh, 1988). A PDU can be a whole product, sub-system, element, component, part or a feature of a product. The information is given as a collection of attributes of the product. Each attribute of a PDU is related to an aspect. An aspect may be cost, tolerance, and functionality. The description of a PDU is created from four basic aspects called 'abstraction mechanisms' and they are as follows:

- Specialisation. This separates different application areas like building, civil engineering, process plant, shipbuilding and terrain mapping.
- Decomposition. Represents how a product can be decomposed into smaller units.
- Life cycle. Distinguishes the stages into requirements, design, planning, build, usage, alterations, and demolition.

- Classification. Identifies occurrences, specific and generic PDUs.

GRAM has had considerable influence as an example of a product modelling method and has been considered as an ISO standard. A full description and evaluation of GRAM is outside the scope of this paper, for more details refer to Gielingh (1988).

1.4.2 AEC building systems model

The AEC Building System Model has been developed within the IGES/PDES ACE Committee, which is a part of the US-national Graphical Exchange Specification (IGES) committee within the Product Data Exchange Specification (PDES) project. The aim of the model is to present high level conceptual schema of an AEC product model. In this case product data refers to the totality of data elements, which completely defines a product for all applications over its expected life cycle (Turner, 1990). The basic concepts of the model are the object. An object may have one or more properties. Most objects go through three phases.

- Generic phase. Exact attributes are not specified.
- Specific phase. Most attributes are known.
- Occurrence. When the location and orientation of a specific object has been determined, exactly or approximately.

An AEC product model is a representation of an AEC project. AEC project types include buildings, process plants, ships, civil projects, and space habitats. AEC project phases include programming; concept design, preliminary design, or planning or design development; detail design; construction documentation; construction planning or construction scheduling; construction; maintenance and operation; redesign, or design for re-use; demolition. A full description and evaluation of ACE is outside the scope of this paper. Refer to Turner (1990) for more details.

1.4.3 RATAS model

The RATAS project attempts to develop a national Finnish system for computer aided design in the construction industry in Finland. The RATAS building model was developed as part of the project to achieve a national building product data model standard. Refer to Björk (1989) and Björk and Penttiala (1993). The RATAS Model describes a building using objects and relations between objects. Two types of relations are involved, the "part-of" -relation and the "connect-to" -relation. An attribute represents properties of the building or parts of the building. An attribute has a domain of values. Objects belong to classes specified with attributes. Lower level classes inherit attributes from higher level classes. To limit the need for data in a representation specific views of the model can be taken. A full description and evaluation of RATAS is outside the scope of this paper. Refer to Björk (1989) and Björk and Penttiala (1993) for more details.

1.5 System Scope

This section places boundaries on the requirements of the active component model. The purpose of the research on which this paper is based is to illustrate how semantics are incorporated within a construction design project by using semantically rich components and, how these components can induce active database behaviour. Ideas developed within the underlying research can be extended to develop a working system. The research carried out focuses on developing: a) an infrastructure to create and manage components, b) an infrastructure to create and manage rules, c) a method of assigning rules to components, and, d) build a design using semantically rich components. Since any object in a construction project can be considered as a component, it is necessary to define the lowest level of granularity for components defined in the underlying research. It is possible to consider the sand, cement and water that make up the bricks and mortar as components. However, to illustrate the active component model on a more practical level the lowest level of component will be lowest level of manufactured object that are used to develop a building such as windows and doors.

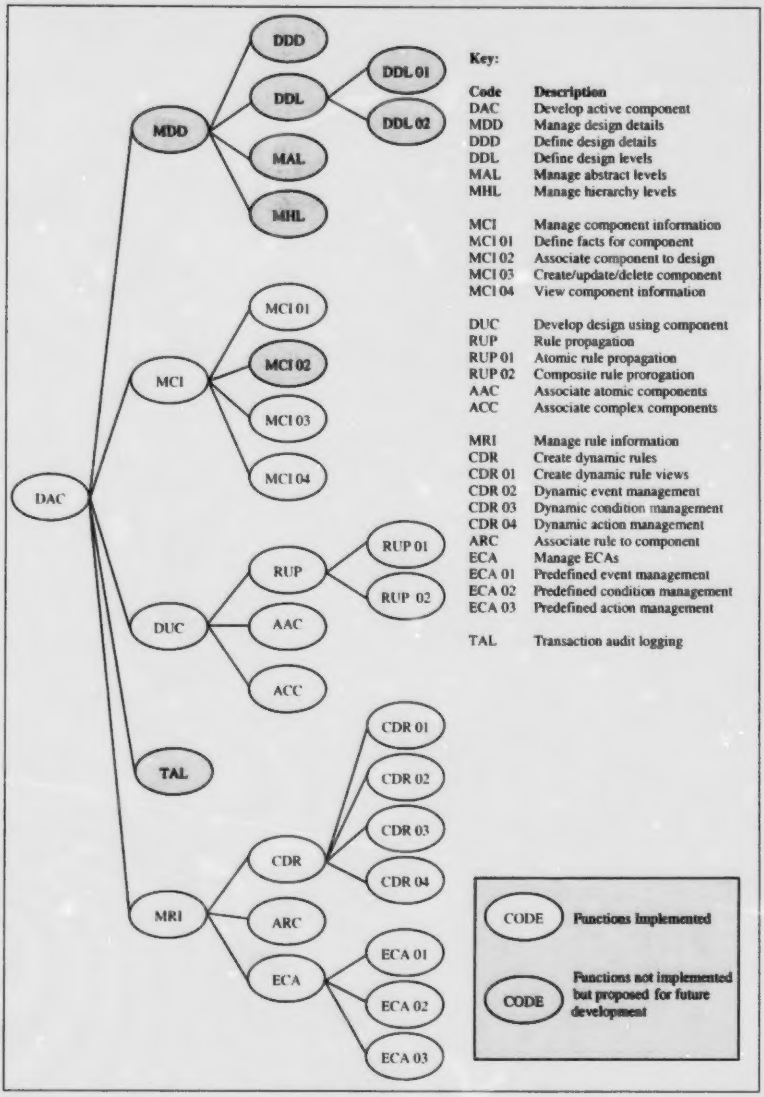
1.6 Functional decomposition

Figure 3 shows the functional decomposition of the active component model. There are five main functional areas: manage design details (MDD), manage component information (MCI), develop design using components (DUC), manage rule information (MRI) and transaction audit logging (TAL). MDD and TAL functions are not implemented but are recommended for future development.

2 Conclusion

This paper has described a successful research effort to build an active database. The database was built on top of an existing mainstream database management system: Oracle. The effort has been mainly directed towards showing that such an approach is indeed feasible. In this regard it has been successful. It must be admitted that it has never been the intention to produce a fully fledged system which could be used in the offices of working construction engineers: principles and theory have been the motivating forces rather than practice and pragmatism.

Finally, this exercise has shown the form that future developments in database theory that will be needed to satisfy complex problems domains such as the construction industry. In this regard this paper points the way forward not only for construction engineers but also for computer scientists.



Key:

Code	**Description**
DAC	Develop active component
MDD	Manage design details
DDD	Define design details
DDL	Define design levels
MAL	Manage abstract levels
MHL	Manage hierarchy levels
MCI	Manage component information
MCI 01	Define facts for component
MCI 02	Associate component to design
MCI 03	Create/update/delete component
MCI 04	View component information
DUC	Develop design using component
RUP	Rule propagation
RUP 01	Atomic rule propagation
RUP 02	Composite rule prorogation
AAC	Associate atomic components
ACC	Associate complex components
MRI	Manage rule information
CDR	Create dynamic rules
CDR 01	Create dynamic rule views
CDR 02	Dynamic event management
CDR 03	Dynamic condition management
CDR 04	Dynamic action management
ARC	Associate rule to component
ECA	Manage ECAs
ECA 01	Predefined event management
ECA 02	Predefined condition management
ECA 03	Predefined action management
TAL	Transaction audit logging

Fig. 3: Functional decomposition

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251 EXPERT VALIDATION OF TALL-D: A KBS FOR TALL BUILDINGS DESIGN

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Abstract

A brief overview of validation of the Tall-D knowledge-based system is presented. The objective of the validation process was to have industry experts participate and to compare the tall building design alternatives generated by Tall-D to those designed in actual projects. Two experts compared test-cases with the designs produced by Tall-D system. These design sessions also enabled the experts to critique the individual cases as well as the overall performance of Tall-D. The overall performance was evaluated through a comprehensive questionnaire on the different features of Tall-D as an automated design tool. The multi-storey test-cases used are actual buildings: Place du Canada, IBM-Marathon and 1000 de La Gauchetière, all located in Montreal. One of the test-cases and the results of the questionnaire-based validation of Tall-D are presented.

Keywords: integrated design system, validation, multi-storey office building, preliminary design, architecture, structure.

1 Introduction

Tall-D is a knowledge-based system for the preliminary design of tall buildings. Tall-D system can generate alternative building configurations and corresponding preliminary structural designs. In the absence of computer-based tools and also due to resource and time constraints, the current preliminary design tasks are mostly restricted to exploring one or two design alternatives, often proceeding with a less than efficient solution. Therefore a computer-based design tool that can be used by designers at the initial stages of a project to explore many design alternatives on a comparative basis will, lead to better and more economical designs than those produced without such a design tool. Following is a discussion of the validation and verification process as applied to the Tall-D system.

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2 Software validation and verification

Validation and verification (V & V) of software are two terms that are generally differentiated from one another. Validation is considered a check on software performance based on output, i.e. performance-oriented. In contrast, verification is a check for conformance to system specifications established at the design stage, i.e. implementation-oriented. The former is a functionality check and the latter, a "structural" check. Validation and verification of knowledge-based systems represents an active research area (Chander 1996, Gupta 1993). In the early days of knowledge-based systems, validation and verification was done on an ad hoc basis. Then, formal methods and tools were developed to check knowledge-bases (Cervera 1993). Since formal V & V is performed against an initial set of specifications, there is a need for formal specifications as well as the definition of acceptability criteria of a KBS. V & V methodologies from conventional software engineering (Sommerville 1993) can also be adapted for KBS. There is nonetheless a lack of widely accepted KBS life-cycle protocol that establishes which V & V activities can be used and when such activities can be performed. The methods and results used in the validation of Tall-D system are reported here, with emphasis on the work with external experts participation.

2.1 Validation methodology for Tall-D

Two methods were used in the V & V of the Tall-D system: (i) incremental verification by random output checking, followed by (ii) validation by external experts. Since the development of Tall-D was not initiated with formal specifications, verification against such a set of specifications did not come into consideration. Tall-D was checked in an incremental manner, as a portion of source code or module was developed. It was a cyclic process in which coding, checking and debugging were performed by the developer. Random output checking by using features of the KBS development tool such as break-point, tracing of firing of rules, explanation function and inspection of objects was part of the routine development and debugging process. Then followed validation performed in collaboration with an expert architect and an expert structural engineer, which forms the focus of this presentation.

3 Validation by external experts

The objective of validation by external experts is to test the Tall-D system with leading designers from the industry who are familiar with the practical aspects of multi-storey building design. The two experts that volunteered their time and project information to evaluate Tall-D were Mr. Antony Niro and Mr. Serge Vézina. Both have extensive experience in the design of multi-storey office buildings. Mr. Niro is an architect consultant (Di Miele Niro Architects, Montreal). Mr. Vézina is a structural engineer at Lalonde, Valois, Lamarre, Valois inc., Montreal, a subsidiary of SNC-Lavalin.

Mr. Vézina selected his recent tall building design, the 1000 de La Gauchetière. Though it represented the high end of the height limitations for Tall-D (50 storeys), it was a successful interactive session that resulted in alternative designs from Tall-D as well as it presented the features of the design system to the expert.

In the other session with Mr. Niro, Place du Canada and IBM-Marathon office towers in Montreal were the test-cases. One common feature of test-cases is that they are all office towers, mostly prismatic with rectangular or square floor plans.

Due to the restrictions on space, not all three test-cases could be presented. One of the three test-cases, the IBM-Marathon building, is presented in a moderate amount of detail as a representative case. For a more comprehensive description of the test-cases and discussion of results the reader is referred to Ravi (1998).

3.1 Design case: IBM-Marathon building

This building is forty seven storeys tall including four mechanical levels. The building has a main tower and two low rise annexes attached to the main tower. This test-case is studied considering only the main tower. The base dimensions of the main tower are 60mx30m. The core to window line distance (column free) is 13.7m. The core dimensions are 30mx9m. Figure 1 shows a typical floor plan of the building under consideration. The design input to generate possible solutions by Tall-D is shown in Table 1. Of the twenty nine alternatives initially generated, twenty three were retained for ranking. Among the evaluated alternatives, Layout#24 ranked second, and due to the number of storeys being forty eight and close to the actual forty seven, is selected by the expert to proceed and inspect the geometry.

After perusal of the structural configuration for Layout#24, and since the plan dimensions of Layout#24 (45m x 40 m) are not close to that of the test-case (which is 60m x 30 m), another alternative Layout#22 ranked third with rectangular floor plan dimensions (55m x 35m) closer to test-case than those of Layout#24, is selected to proceed with geometric configuration and structural design. Figure 2 shows a structural configuration for Layout#22. Different lateral system alternatives are generated by Tall-D. In all, four alternative structural system schemes are generated each with geometric information. Each scheme has alternative column spacing on the perimeter. The four types of structural schemes generated are described below, in no particular order:

a) All-concrete, frame shearwall scheme. A system that combines shearwalls and rigid frames to provide adequate lateral-load resistance for tall buildings. The actual building uses this system.

b) Steel framed tube with concrete shearwall. Closely spaced columns on the perimeter along with a shearcore provides great flexibility to design for lateral loads for a tall building like this one.

c) All-steel, braced perimeter frames on the exterior faces of the building. Provides greater flexibility for planning occupant space as opposed to the next scheme of interior braced frame.

d) All-steel, braced frames on the interior. The bracings are on the inside where they are easier to conceal. However if large open spaces or greater flexibility is needed, this may not be a suitable choice.

The details of the column sizes and quantities for the above first two schemes for each column spacing alternative are generated by Tall-D and inspected the expert. The other two alternatives being all-steel structural schemes were not inspected by the expert. Two other structural systems are identified by Tall-D as suitable for use in these buildings, but did not complete the design due to the incomplete state of their implementation. These two are framed end channel scheme and belt truss with braced frame scheme. When the percentage of core area (with respect to gross floor area) is reduced to 15% from the previous 20% as suggested by the expert designer, Tall-D produced an additional alternative (labelled here Layout#23 with plan dimensions 55mx30m and 49 storeys) which is yet closer to the test-case dimensions.

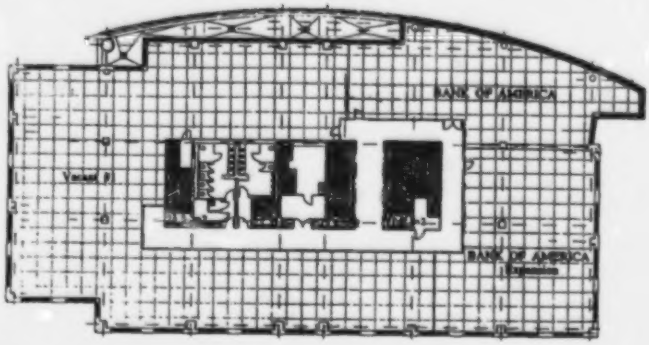
Table 1: Input parameters for example design-case

Parameter	Value
Net Floor Area required	65790 m^2
Maximum number of floors	50
Dimensions of Plot	130 x 70 m
Approximate Budget [1995$]	$200 millions

Table 2 shows a comparison between the as-built design parameters on the left and the Tall-D generated parameters on the right - Layout#22. For purposes of comparison with the actual building the values for frame-shrearwall scheme for the alternative with perimeter column spacing of xx:6.9m and yy:7.0m are used. The sizes of the structural members as well as the spacing of columns are comparable between the test-case and as designed by the Tall-D system. Tall-D has selected a concrete compressive strength of 60MPa for the initial layout selection Layout#24. The columns are spaced at 7.5m with square sizes of 850mm at base and 450mm at 35th floor. Since the expert preferred the rectangular proportions of Layout#22 the rest of the design was carried out for the same. The corresponding Tall-D designed values for Layout#22 are 55MPa, 6.9m column spacing, square column sizes of 850mm at base and 350mm at the 35th floor. The corresponding actual values are 55MPa concrete, 9m column spacing, sections of 1000mm at base and 600mm at 35th floor (according to the external expert). The somewhat smaller sections of columns for Tall-D design can be attributed to the smaller spacing suggested by Tall-D. The smaller clear span of 9.7m in the design simulation as opposed to the actual value of 13.7m would also impose lesser gravity loads on the perimeter columns, though the occupant space is also less. It can therefore be said that Tall-D columns appear reasonably sized.

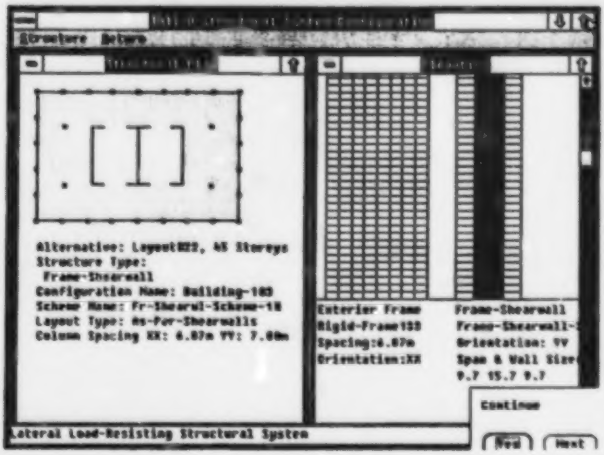
Comparing the quantities for the different alternatives, one can find a range of quantities. Though these material quantities are for the lateral-load resisting system alone, they are an indication of the footprint of the structure. It can be said with some degree of confidence that the relative measure of these quantities are an indication of the material costs. Though material costs are not always the binding factor in the selection of a system, all things being equal this factor can certainly be used to select an alternative from those presented by Tall-D. As an example, the alternatives with perimeter column spacing of 4.6m and 4.4m have 143 m^3 and 177 m^3 less concrete volume than the two subsequent alternatives respectively (column spacing 6.9m / 7.0m and 6.1m / 5.8m). Similarly for the steel framed tube alternative the steel tonnage for the columns alone ranges from a low of 261 tonnes to 504 tonnes which makes the alternative with the perimeter column spacing of 7.9m and 8.7m the preferred alternative as opposed to 4.5m or 3.0m perimeter column spacing. The quantities are better used as a relative measure than an absolute conclusive parameter. Thus Tall-D generated material quantities provide an evaluation of the structural systems generated, and is appropriate for preliminary design purposes.

Ranked first among the gravity system alternatives for the frame shearwall structural system generated by Tall-D is the concrete joist slab system with a total depth of 1100mm inclusive of joist depth 400mm. The other alternatives are, in order, waffle slab, one-way slab with beams,



IBM-Marathon Building	Year Built: 1992
1250 boulevard René-Lévesque	Plan Dimensions: 60mx30m
Montreal	Sketch not to scale
Source: Excerpt from space planning drawings (A. Niro, Architect)	

Fig. 1: Typical floor plan (level ten) of IBM-Marathon building



```
Alternative: Layout#22, 45 Storeys
Structure Type:
 Frame-Shearwall
Configuration Name: Building-103
Scheme Name: Fr-Shearwl-Scheme-18
Layout Type: As-Per-Shearwalls
Column Spacing XX: 6.07m YY: 7.00m
```

```
Exterior Frame          Frame-Shearwall
Rigid-Frame133          Frame-Shearwall-
Spacing:6.07m           Orientation: YY
Orientation:XX          Span & Wall Size
                        9.7 15.7 9.7
```

```
Lateral Load-Resisting Structural System
```

Fig. 2: Structural configuration alternative for Layout#22 of design-case

Table 2: Comparison of as-built IBM-Marathon building with Tall-D design

Building Parameter		As Built(Tower)		Tall-D (Layout#22)	
Plan dimensions		60m x 30m		55m x 35m	
Core dimensions		30m x 9m 16-35floors	41m x 9m 1-15 floors	24.6m x 15.7m	
Storeys (+mechanical levels)		43 (+4)		43 (+ 2)	
Floor area Gross::Net (m^2)		84600 :: 65790		86625 :: 66168	
Cost of building ($ millions)		(148[1])		72	
Lateral-load resisting system		Frame-Shearwall		Frame-Shearwall[2]	
Material grade of columns		55MPa		55Mpa	
Column spacing on perimeter		*Front:xx*	*Side:yy*	*Front:xx*	*Side:yy*
		9.0m	7.5m	6.87m	7.00m
Column sizes on building perimeter (mxm)	Ground level	1.0 x 1.0	1.0 x 1.0	.85 x .85	.85 x .85
	Levels 15-11	n/a	n/a	.75 x .75	.75 x .75
	Levels 25-21	n/a	n/a	.65 x .65	.65 x .65
	Level 35	0.6 x 0.6	0.6 x 0.6	.35 x .35	.35 x .35
	Levels 48-46	n/a	n/a	.30 x .30	.30 x .30
Number of shearwalls		6 at Base; 4 at 43rd Floor		3 throughout	
Shearwall concrete, size and thickness		60MPa; 9m long; 525mm		55MPa; 15.7m; 600mm	
Gravity-load resisting system		n/a		Concrete Joist slab and others (see p. D2-11)	
Clear span (front/back and sides)		13.7m⇕ and 15.0m⇔		9.7m⇕ and 15.2m⇔	
Depth of gravity system beams		n/a		1.10m for joist beam-slab system	

band-beam with slab and finally hollow core slab. The ranking is based on known in-place cost of construction (Means 1996), not on estimated quantities nor on other merits of the gravity systems. Similar rankings for the steel framed tube schemes are, again, in order of preference, truss beam, haunch beam, tapered beam, parallel beam and stub girder. The truss beam is 680mm deep with additional steel deck 70mm thick as well an equal depth of concrete topping.

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[1] This cost includes the tower, low-rise part, under-ground parking, site preparation etc.; Tall-D cost is only that of the tower, above ground. The actual cost for the as-built tower is 90 million.

[2] Information on all structural systems alternatives proposed by Tall-D could not be presented due to limitations on space.

4 Questionnaire-based evaluation of Tall-D

A questionnaire with 40 different queries categorised under seven headings was used to elicit an assessment of Tall-D from the experts. The questionnaire along with the expert evaluations is shown in Table 3(a) and 3(b). The scoring is based on a numeric scale of 1 to 5 with 1 being "strongly disagree" and 5 being "strongly agree". A few of the features such as member scaling for gravity load-resisting system being under-designed invited a grading of 2 from the engineer. Otherwise the system was graded favourably in all other categories. On a few items the two experts differed significantly in their assessment. On the relevance of floor plans generated - the architect scores 5 versus a 3 from the engineer. Similarly, the item - display of results - got 2 from the engineer and 4 from the architect. Apart from perceptions, one reason for this is the architect performed two designs - one of moderate height and the other much taller - compared to only one by the engineer. Therefore the former was exposed to a larger variety of configurations and corresponding number of text screens, giving a better demonstration of the feature. Barring a few items out of some 40, there is general agreement in their assessment. Both experts give 3 for approximate costs indicating it needs improvement and both are highly enthusiastic of the utility of Tall-D. The average of scores assigned by the two experts under different categories may be studied to understand Tall-D performance. The average scores show the engineer scoring from a low of 3.0 in cost and quantity to a high of 4.6 in utility of Tall-D categories. The architect scored a low of 3.6 on design process issues and user interface with the high being again utility of Tall-D with a score of 4.4. Incidentally the "Utility of Tall-D" category consists of items such as useful to perform preliminary design (both score 5), useful to explore design possibilities (again both score 5) and useful tool for multi-storey building design (scores of 5 and 4). This clearly demonstrates a principal aim of this work is realised which is the development of a tool for preliminary design. Since an architect along with an engineer considered Tall-D from their points of view and responded well, it can reasonably be said that domain integration between the architectural and structural design areas has been successfully demonstrated. Thus the process of validation of Tall-D by the experts not only served to compare practical designs to Tall-D generated designs, but was also useful to perform an overall evaluation of the computer-based tool for preliminary design tasks. It also brought out the fact that a KBS could be deployed in practice, with expert evaluation and endorsement.

5 Conclusion

Tall-D was very well received and evaluated by the two experts who were involved at this step of the validation process. A few weaknesses in Tall-D were also identified. The architect pointed out that the core size was large for relatively smaller sized buildings. For rectangular floor plans, slightly smaller clear spans were generated by Tall-D in the short-span direction (yy) of the building compared to the actual designs. A noticeable weakness in Tall-D member sizing is related to steel beams located on the building perimeter and moment-connected so as to participate in lateral load resistance. Gravity system sizing was in some cases under-designed. Gravity system designs produced by Tall-D were considered by the structural expert as adequate from the strength point of view but could be inadequate from the serviceability (structural) point of view.

Table 3(a) Comparison of the Tall-D Evaluation Scores by Expert Structural Engineer and Expert Architect.

Tall-D Evaluation Criteria	(5) Strongly Agree (1) Strongly Disagree	
	Engineer	Architect
I. ***Architectural Considerations (flexibility etc.)***		
Relevance of floor plans generated	1 2 [✓ 3] 4 5	1 2 3 4 [✓ 5]
Core location(s) appropriate	1 2 3 [✓ 4] 5	1 2 3 [✓ 4] 5
Relevance of column layouts generated	1 2 3 [✓ 4] 5	1 2 [✓ 3] 4 5
Ranking of initial floor plans	1 2 [✓ 3] 4 5	1 2 3 [✓ 4] 5
II. ***Preliminary Structural Design Considerations.***		
IIa. ***Geometric Configuration of Lateral Load-Resisting System (LLS)***		
Exploration/Generation of possible LLS alternatives	1 2 3 [✓ 4] 5	1 2 3 [✓ 4] 5
Compatibility of LLS with initial floor layout		
Of plans with rigid-frames	1 2 3 [✓ 4] 5	1 2 3 [✓ 4] 5
Of plans with braced-frames	1 2 3 [✓ 4] 5	1 2 3 [✓ 4] 5
Of plans with shearwalls	1 2 3 [✓ 4] 5	1 2 3 4 [✓ 5]
Of plans with tubular structure	1 2 3 [✓ 4] 5	1 2 [✓ 3] 4 5
Concrete Column Sizing	1 2 [✓ 3] 4 5	1 2 3 [✓ 4] 5
Steel Column Sizing	1 2 [✓ 3] 4 5	1 2 3 [✓ 4] 5
Concrete Shearwall Sizing	1 2 [✓ 3] 4 5	1 2 3 [✓ 4] 5
IIb. ***Geometric configuration of Gravity Load-Resisting System (GLS)***		
Exploration/Generation of Relevant alternatives	1 2 3 [✓ 4] 5	1 2 3 [✓ 4] 5
Concrete beam sizing	1 2 [✓ 3] 4 5	1 2 3 [✓ 4] 5
Steel beam sizing (rolled sections, stub girders, castellated, haunch, tapered beams, joist/truss etc.)	1 [✓ 2] 3 4 5	1 2 3 [✓ 4] 5
Concrete slab sizing (flat-slab, waffle, joists, oneway and twoway slabs etc.)	1 [✓ 2] 3 4 5	1 2 3 [✓ 4] 5
Steel deck-slab sizing	1 [✓ 2] 3 4 5	1 2 3 [✓ 4] 5

Table 3(b) Comparison of the Tall-D Evaluation Scores by Expert Structural Engineer and Expert Architect.

Tall-D Evaluation Criteria	Engineer	Architect
III *Design Process Issues and User Interface for Tall-D*		
Consideration of relevant constraints	1 2 [✓ 3] 4 5	1 2 3 [✓ 4] 5
Ability to redefine criteria	1 2 3 [✓ 4] 5	1 2 [✓ 3] 4 5
Ability to go back to generate different schemes	1 2 3 [✓ 4] 5	1 2 3 [✓ 4] 5
Sketch Floor Layout Graphical Display	1 2 [✓ 3] 4 5	1 2 [✓ 3] 4 5
Structural Elevation Graphical Display	1 2 3 [✓ 4] 5	1 2 [✓ 3] 4 5
Display of Results - Text Screens	1 [✓ 2] 3 4 5	1 2 3 [✓ 4] 5
Explanation of Results	1 2 [✓ 3] 4 5	1 2 3 [✓ 4] 5
Clarity of Menus and prompts	1 2 [✓ 3] 4 5	1 2 3 [✓ 4] 5
IV *Approximate Analysis of frames for lateral loads*		
Rigid Frame system	1 2 3 [✓ 4] 5	1 2 3 [✓ 4] 5
Braced frame system	1 2 3 [✓ 4] 5	1 2 [✓ 3] 4 5
Frame-Shearwall system	1 2 3 [✓ 4] 5	1 2 3 4 [✓ 5]
Tubular frame system	1 2 [✓ 3] 4 5	1 2 3 [✓ 4] 5
V *Cost and Quantity Estimation*		
Approximation of overall project cost	1 2 [✓ 3] 4 5	1 2 [✓ 3] 4 5
Relative structural cost of vertical structuarl system	1 2 [✓ 3] 4 5	1 2 3 [✓ 4] 5
Relative structural cost of floor system	1 2 [✓ 3] 4 5	1 2 3 [✓ 4] 5
Structural quantities estimation	1 2 [✓ 3] 4 5	1 2 3 4 [✓ 5]
VI *Utility of Tall-D*		
Overall concept of System	1 2 3 [✓ 4] 5	1 2 3 [✓ 4] 5
Useful to perform preliminary design	1 2 3 4 [✓ 5]	1 2 3 4 [✓ 5]
Useful tool for multistorey buildings design	1 2 3 4 [✓ 5]	1 2 3 [✓ 4] 5
Useful to explore design possibilities	1 2 3 4 [✓ 5]	1 2 3 4 [✓ 5]
Useful as learning tool for students	1 2 3 [✓ 4] 5	1 2 3 [✓ 4] 5
Overall performance	1 2 3 [✓ 4] 5	1 2 3 [✓ 4] 5

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252 THE DYNAMIC DEFINITION OF DESIGN ELEMENT SPECIFICATIONS VIA A PRODUCT SUPPLIER DATABASE WEB-SITE

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Abstract

The AIC Research Group at the University of Salford have been involved in a government funded project that aimed to develop an integrated multi-user distributed construction project database - WISPER (Web-based Integrated Shared Project EnviRonment). The objective of the project was to develop a working system capable of demonstrating the future direction of information integration with the project partners' businesses. This paper presents the development of the specification application that aims to demonstrate the potential for design elements to be specified directly from a product database Web site.

Keywords: Design element specifications, IFC, integrated distributed construction project database, three-tier client-server architecture, STEP Part21.

1 Introduction

The Internet with its open standards and accessibility is fast evolving into a powerful environment for supporting distributed group work. Originally the Web was a static two-tier client-server unidirectional environment for the publishing and broadcasting of electronic documents. However, demands for dynamic content is beginning to change that. The Web is being transformed from a publishing technology into a full-blown client-server medium, with the potential to run line-of-business applications and to deal with the complex requirements of multistep business-to-business and consumer-to-business transactions (Orfali et al. 1997).

This paper presents the specification application that has been developed as part of the implementation of a new generation of construction integrated environments. The application aims to demonstrate the potential for next-generation Web technology together with the IFCs to support the direct specification of design elements from a product database Web site. Such an

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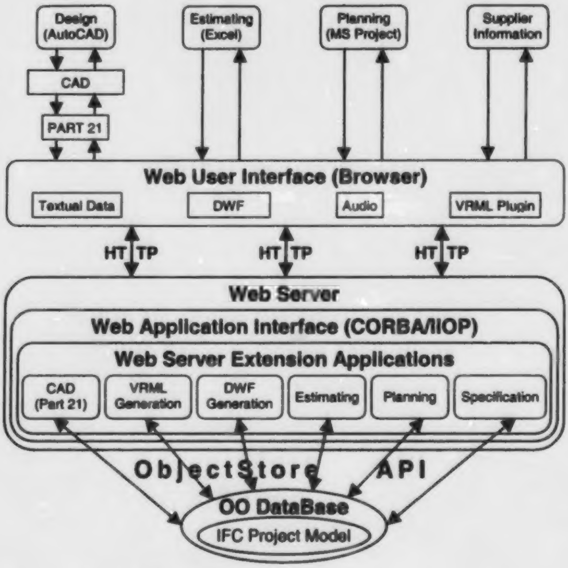


Fig. 1: Overview of WISPER

application enables the designer to retrieve their defined specifications (including technical information) in a standard format directly via the Web, and to upload this information into the project database to be accessed by the other applications, e.g. CAD, Estimating, etc. In addition, the paper provides a brief overview of the integrated distributed construction environment, the implemented supporting applications and the IFC object model architecture.

2 WISPER - Web-based integrated shared project environment

2.1 Three-tier client-server architecture

As shown in Fig. 1, the architecture of WISPER uses a three-tier client-server infrastructure to demonstrate the integration between detailed design, building element based cost estimating, and construction scheduling, in addition to a VRML viewer that allows the graphical querying of a project database (Alshawi et al. 1998; Faraj et al. 1998a, 1998b; WISPER 1998). Within a three-tier architecture each facet of the application, i.e. user interface, logic, and database, is isolated providing benefits such as maximum control, scalability, and flexibility (Campbell 1997; Orfali et al. 1997).

2.2 IFC object-oriented project database

At the lowest level of the system architecture (Bottom Tier), the main project database has been developed using the ObjectStore object-oriented database management system together with the implementation of Java classes derived directly from the Final Version 1.5 of the International Alliance for Interoperability's (IAI) Industry Foundation Classes (IFCs). The IFCs are an initiative by leading construction software vendors to produce a standard data model for interoperability of construction related software applications (IAI 1999). The project model for the Final Version 1.5 of the IFCs has been published using EXPRESS. EXPRESS is a formal language developed by the STEP community for the description of data models (STEP Tools, Inc. 1999a; UKCIC 1999). To map this schema to ObjectStore, ST-Developer was used to convert the IFC schema from EXPRESS to a set of programming language classes (pure Java classes). ST-Developer is a Step Tools product that provides a comprehensive, stand-alone set of software development tools for handling the complexities of the STEP standard, which can be used to build software that works with STEP data in object-oriented databases, relational databases, and traditional files (STEP Tools, Inc. 1999b). ObjectStore utilities are then used to read the Java classes to create the IFC project database schema. This schema can then be used and instantiated by the various construction applications.

2.3 Application servers

Using Web client-server technology, i.e. Web Server Extensions (Java WAI applications), applications have been written in Java for the two-way exchange of information between the project database and existing software, i.e. AutoCAD, Excel, MS Project scheduling package, etc. (Middle Tier). WAI is a CORBA-based (Common Object Request Broker Architecture) programming interface that defines object interfaces to the HTTP request/response data and server information. Via WAI, the Web applications accept an HTTP request from a client (Web browser), process it, and return a response to the client.

2.4 User interface

Finally, the top tier of the system provides the interface to the overall system. The user interface has been implemented as a set of Web pages and other commercial applications to support the different construction experts that may need to interact with the environment. The user interface enables the user to submit, retrieve, process and manipulate data. Users can perform operations on the project data by selecting the appropriate menu item on a specific Web page. Each menu item references a URL that submits an http request to the server. The Web server assigns the responsibility for processing the HTTP request to the CORBA objects.

WISPER uses the concept of a 'project Web site' as a first point of access for all shared project information. Each new project has its own Web site, allowing project information to be accessed through an internal network (Intranet) or through the wider global Internet. Furthermore, existing security mechanisms such as; password protection, certificates, IP address filtering, etc., ensures the security of the project information by controlling access to the project Web pages.

2.5 Implemented applications

- *CAD (design)*: Due to the lack of availability of commercial IFC compatible CAD systems, the research team has implemented their own CAD system that uses the AutoCAD-14 geometry engine. The application supports both newly created and existing projects. The 'Newly Created Project' application enables the user to create new building designs and to share information with other construction applications. Data in the application is saved in STEP Part 21 file format. The 'Existing Project' application allows the user to populate the database from a STEP Part 21 file. Part 21 files of existing projects can therefore be loaded to the database for amendment and saved as Part 21 file format.

- *VRML*: The application generates the VRML model of the design and displays the results within a Web browser. The user can interact with the design and retrieve other construction data associated with the object or project as a whole that are found in the database from the virtual reality model.
- *DWF*: DWF (Drawing Web Format) is a graphics format for the transfer of drawings over Intranets and the Internet. The application parses the database for the building elements that exist in a project and generates the DWF representation of each element.
- *Estimating*: Generates the elemental IFC cost group objects within the central project database from the design, before returning this information into Excel. The user add costs to the cost groups in Excel and uploads the CSV file into the project database, i.e. adding costs, date and time, etc. to the previously generated cost group objects. Finally, a cost summary of the project can be viewed in terms of both element type and storey.
- *Planning*: Generates the work group objects within the central project database from the design, before returning this information into MS Project scheduling package. Next, the user adds duration and links/dependencies and uploads the CSV file into the project database, i.e. adding the durations and links, to the previously generated work group objects.

3 IFC property type definitions & shared property sets

3.1 IFC object model architecture overview

The IFC Object Model architecture provides a modular structure for the development of model components. The architecture consists of four layers, which use a strict referencing hierarchy. Within each layer a number of grouped modules exist (IAI 1999).

- *Independent Resource Layer*: Independent Resources are ideas that do not rely on classes within the Kernel for their existence, e.g. geometry, cost, etc. Resources form the lowest layer in the IFC Model Architecture and can be used or referenced by all classes in other layers.
- *Core Layer*: The Core contains two sub-layers. The Kernel provides basic, shared concepts in AEC/FM projects and determines the model structure and decomposition. The Kernel includes fundamental concepts concerning the provision of objects, relationships, type definitions, attributes and roles. Kernel classes may only reference classes in the Independent Resources. A Core Extension is a specialisation of classes defined in the Kernel such as Product and Process. Primary relationships and roles are also defined within the Core Extensions.

- *Interoperability*: The Interoperability layer provides specialised, well-defined interfaces for one or more Domain Models. This provides for outsourcing of Domain Model development whilst retaining control over the key structuring and framework requirements of interoperability.
- *Domain Specifications*: Domain Models provide further model detail within the scope requirements for an AEC domain process or a type of application. Each is a separate model that may use or reference any class defined in the Core and Independent Resource layers. Examples of Domain Models are Architecture, HVAC, FM, Structural Engineering etc.

3.2 Type definitions

The IfcPropertyTypeResource defines the basic capabilities for Property definitions that can be attached to objects and relationships. This Resource module enables a "Type" of an Element to be defined, which in turn establishes a standard to be used many times in a project. A standard type is established through the definition of a set of Properties or Characteristics that will be held constant for all occurrences in the project model. Therefore, a single record of these attributes is associated with the Type Definition object rather than with each occurrence of the element.

For example, in the case of doors and windows, an IfcPropertyTypeDef object is created for each type of element and is referenced by those IfcObjects, e.g. IfcDoor, IfcWindow, etc., to which it is associated. The IfcPropertyTypeDef class provides for the capability to define a set of properties at runtime, since they do not need a separate static class definition, and share the values of the set of properties among multiple instances of the same class of objects. In addition, the IfcPropertyTypeDef class possesses a number of attributes. 'TypeDefName' represents the name of the specific Property Type Definition, 'TypedClass' refers to the name of the class for which the object defines a type, e.g. IfcDoor, IfcWindow, etc. and 'GenericType' specifies the IFC generic type designation, e.g. SingleSwing, FixedCasement, etc.

3.3 Shared property sets

Each Type Definition has a reference to an IfcSharedPropertySet. An IfcSharedPropertySet defines a set of type driven properties (and is therefore defined as part of the IFC standard) that are shared by multiple instances of a semantic object, i.e. each semantic object instance (having the same property values) shares by reference a single instance of the IfcSharedPropertySet with particular property values.

The type definition for a single swing door has a reference (in the Sharedproperties attribute) to a 'Pset_DoorSglSwing' shared property set, that in turn, has references to two further shared property sets, 'Pset_DoorType' and 'Pset_DoorPanel', that are held in the 'Hasproperties' attribute list. The 'Pset_DoorType' shared property set contains the common shared values/properties for the specific type of single swing door. These properties relate to information such as the reference ID for the door type within a particular project, specific description of the door type, manufacturer, nominal and rough heights and widths, fire, thermal and acoustic ratings, whether the door is designed for use in exterior walls, etc. Each property is created as IfcSimplyProperty object. IfcSimpleProperty defines an attribute class in which the unique description/name of the property ('Descriptor') and a reference to the property's value ('ValueComponent') is held. The actual value of the property is held in an IfcMeasureValue object (part of the IfcMeasureResource module) based upon its type, e.g. Ifcdescriptivemeasure, Ifcnumericmeasure, etc.

The properties associated with the doorframe such as description, depth, thickness, etc., are also contained within a shared property set ('Pset_DoorWinFrameType'), which is referenced in the 'Hasproperties' attribute list of the 'Pset_DoorType' shared property set. Again, a simple property and associated measure value object represents each of the properties. An IfcMaterial object represents the material property of the doorframe. IfcMaterial is part of the Material model within the IfcPropertyResource module that provides the facility to specify the material from which an object is composed. The IfcMaterial property together with the simple properties is referenced in the 'Hasproperties' attribute of the 'Pset_DoorWinFrameType' shared property set.

Finally, the 'Pset_DoorPanel' shared property set contains the properties (or references to simple and material property objects) for the door panel/leaf associated with the single swing door type definition, e.g. height, width, thickness, material, etc.

In a similar manner, the type definition for a fixed casement window has a reference to a 'Pset_FixedCasement' shared property set, that in turn, has a reference to a further shared property set, 'Pset_WindowType'. The 'Pset_WindowType' shared property set contains the common shared values/properties (references to simple property objects) for the specific type of fixed casement window, e.g. ID reference, description, manufacturer, dimensions, etc. The 'Pset_DoorWinFrameType' shared property set for the window frame is also referenced in the 'Hasproperties' attribute of the 'Pset_WindowType' shared property set.

4 Product database

For the purpose of the prototype, a product relational database was developed using MS Access. The information relating to each particular type of component/element is held in a single table within the product database, i.e. Door Frames, Door Leaves, and Windows. The structure of each table is primarily based upon the properties specified in the IFC property sets, i.e. Pset_DoorPanel, Pset_DoorType, Pset_WindowType, etc. For example, the Door Leaves table comprises fields relating to information such as manufacturer, product name, height, width, thickness, material, fire, thermal and acoustic ratings, suitability for external or internal exposure, etc. In addition, the Door Leaves and Windows tables have a field to hold a reference to an image file of each specific product.

5 Specification web server extension applications

The Specification application has been implemented as two Netscape Web Application Interface (WAI) Web server extension applications written in Java. WAI is a CORBA-based programming interface that defines object interfaces to the HTTP request/response data and server information. Using WAI, Web applications can be written to accept HTTP requests from a client, process them, and return the response to the client. The end user does not need to know where the data resides or which server is processing it (Netscape 1999).

The user interacts with each application through a specific set of Web pages. The first of the applications enables the user to define the necessary door and window specifications from the suppliers database, which are returned to the user as IFC type definitions, shared property sets, etc., in the form of a STEP Part 21 file. Once the Part 21 file has been returned, the user can upload this file into the IFC object oriented project database, via the second of the WAI applications.

Each WAI application creates and registers CORBA objects (OMG 1999) with the respective Web server, i.e. suppliers database and IFC project database. The Web server associates each of these objects with a specific URL of the form: *http://server//iiop/object_name*. The *server* part of the URL identifies the name of the machine on which the Web server runs, while *iiop* (Internet Inter ORB Protocol) passes request or service replies through the internet, and the *object_name* is the name by which the application is registered and identified by the ORB (Object Request Broker). Once the URL is accessed the Web server delegates the responsibility for processing the HTTP request to the CORBA objects.

5.1 Specification definition WAI application

Fig. 2 shows an overview of the specification definition WAI application. The application receives an initial request from the hyperlink of a selected menu

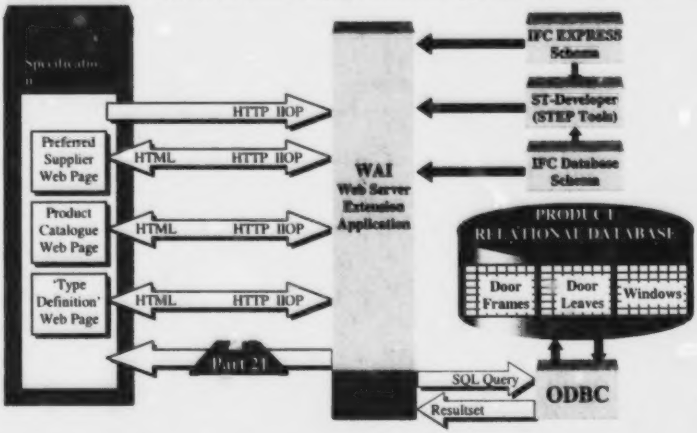
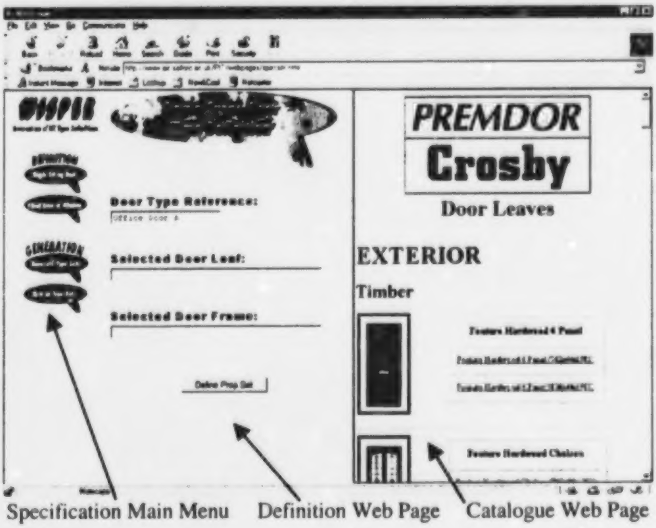

Specification
HTTP IIOP
Preferred Supplier Web Page
HTML
HTTP IIOP
Product Catalogue Web Page
HTML
HTTP IIOP
'Type Definition' Web Page
HTML
HTTP IIOP
Part 21
WAI
Web Server Extension Application
IFC EXPRESS Schema
ST-Developer (STEP Tools)
IFC Database Schema
PRODUCT RELATIONAL DATABASE
Door Frames
Door Leaves
Windows
SQL Query
Resultset
ODBC

Fig. 2: Schematic overview of the specification definition WAI application

item ('Single Swing Door' or 'Fixed Casement Windows') on the specification Web page (Fig. 3). Using the value of a parameter received from the hyperlink, i.e. using the HTTP GET protocol, the application connects to the product database via JDBC and ODBC, and retrieves the names of suppliers of the type of element selected. JDBC is a Java API for executing SQL statements on relational databases. Via the ODBC API, JDBC enables Java programs to establish a connection with a relational database, send SQL statements, and process the results (Sun Microsystems, Inc. 1999). The supplier names received from the SQL query are placed as options within a selection list of a dynamic HTML page, which is then returned to the user. By submitting the selection of a particular supplier/manufacturer from the list, using the HTTP POST protocol, a further request is sent to the application. Upon receiving this request, the application connects to the products database, retrieves the necessary information such as element description, image file name, etc., and dynamically generates a catalogue HTML page of specific elements for the selected supplier, before returning the page to the user.

In the case of windows, a catalogue of window units is returned to the user. However, from the point of view of doors, the application initially returns a catalogue of door leaves (Fig. 3). Within the HTML catalogue page, each specific element's description is created as a hyperlink to a client-side JavaScript function. Client-side JavaScript statements embedded in an HTML page can respond to user events. When a user selects a particular element in the catalogue HTML page, the JavaScript function copies the element's description into the respective text input form element on the definition Web page, i.e. 'Window' or 'Door Leaf' input box. Following the selection of a door leaf, and the subsequent copying of its



Door Type Reference:
Office Door A

Selected Door Leaf:

Selected Door Frame:

Specification Main Menu　Definition Web Page　Catalogue Web Page

Fig. 3: Specification web pages

description into the 'Door Leaf' text box, the JavaScript function triggers a request to the application to return a catalogue HTML page of door frames suitable for the door leaf selected. Using the door description passed in the request, the application retrieves the descriptions of the suitable door frames from the database, dynamically generates the catalogue HTML page, including client-side JavaScript, etc. and returns the HTML page. When the user selects a door frame from the catalogue Web page, the description of the door frame is copied into the 'Door Frame' text input form element of the single swing door type definition Web page (Fig. 3). Within the type definition Web page, the user specifies the element type reference in the 'Type Reference' input box, i.e., the reference ID property of the 'Pset_DoorType'/'Pset_WindowType' shared property set. Once the user has completed defining a type definition/specification, i.e. specified the element type's reference and selected the element/components associated with the element type, a request is sent to the application via the 'Define Definition' submit button on the type definition Web page. The application responds to the request by holding the type reference and the associated element/component description(s) passed in the request, which provides the opportunity for additional type definitions to be defined.

Following the definition of the required door and window type definitions, a final request is passed to the application to generate and return the type definitions previously specified in Part 21 exchange file format, i.e. an EXPRESS-driven data exchange file specification (STEP Tools, Inc. 1999b; UKCIC 1999). The application acts upon this request by connecting to the product database and retrieving the various properties associated with the element(s)\component(s) specified for each type definition, e.g. dimensions, supplier, fire rating, material, etc. ST-Developer uses the EXPRESS IFC schema and the corresponding IFC Project Database schema (Java classes), together with the properties retrieved from the product database to generate the complete IFC Type Definitions for those specified. The complete IFC Type Definitions are written out to a Part 21 physical file, which is returned to the user.

5.2 Type definitions upload WAI application

The second WAI application resides on the project database Web server. By sending the Part 21 physical file of the previously defined type definitions, via a file input form element using the HTTP POST protocol, the application is delegated the responsibility of uploading the file to the IFC project database. ST-Developer uses the IFC schema and the corresponding IFC project database schema to create the Java objects that correspond to the project instances defined in the Part 21 file. Using ObjectStore utilities, the Java objects are instantiated in the IFC project database. Once uploaded to the IFC project database, the CAD application can download the Type Definitions and attach them to the relevant design elements as they are being designed.

6 Conclusions

This paper has presented a specification application that has been developed as part of the implementation of a new generation of computer integrated environments. The integrated multi-user distributed construction project database environment, WISPER, is based on a three-tier client-server architecture, in which the user interfaces, business logic and database are all kept separate. The development of the object-oriented project database has been achieved via the implementation of the IFC Final Version 1.5 project model. In addition, Web technology was used to develop the user interfaces and enable the communication of distributed applications, i.e. Web pages and Web server extensions, respectively.

The specification application aims to demonstrate the potential for design elements to be specified directly from a product database Web site. From the specification Web pages on the project Web site, the user can access the product catalogues of their preferred suppliers. The user is able to select products directly from the catalogue and define the required specifications. Finally, the user requests the product database WAI application to return a Part 21 file of the IFC Type Definitions for the specifications defined, which is subsequently uploaded into the IFC project database to be downloaded by the CAD application and attached to the respective design elements. Such an application would create a closer link between suppliers and the design process - bringing supplier information early into the design process. This would also potentially enable suppliers/manufacturers to influence the design.

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253 EXPLORING AND COMPARING DESIGNS: THE SAME GAME?

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Abstract

Design space explorers are computer programs that play on an exploration metaphor to support design. They assist designers in creating alternative designs by structuring the process of design creation in a space of alternatives. Subsidiary metaphors relevant to design space explorers are *generation, navigation* and *re-use*. The SEED project has developed a knowledge-level representation for a design space explorer. This paper sketches typed feature structures as a formal system in which a design space explorer and its knowledge level might be implemented. First, informal and abstract properties of typed feature structures suffice to build a sketch of the behaviour of a design space explorer. Second, using an example based on single-fronted cottages (a common Australian housing type), we outline the typed feature structure machinery most relevant to design space exploration. Finally we argue that the same mechanisms that enable design space exploration are applicable to evaluation.

Keywords: Representation, evaluation, generative design

1 Introduction

This paper is about the representation of designs through the typed feature structures formalism. It presents an informal sketch aimed at developing intuition about the representation and its fundamental computations. The representation was developed in the context of creating a design space explorer in which designers would search a space of possibilities for designs meeting a possibly changing set of criteria.

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Its relevance to the present conference theme arises because it addresses, in a particularly rigourous way, the comparison of representations for structural similarity. It is well-known that in representing, for instance, a building envelope, a rich set of relations encompassing both form and function must be presented in order for an automatic evaluation to proceed. It is perhaps less well recognised that much evaluation can be accomplished, or at least pre-processed, by direct comparison between the symbol structures of representations. This is what the deemed-to-comply provisions of codes do in an informal way. We proceed with a sketch of the design space explorer knowledge and symbol level representations, arriving finally at a re-use mechanism that is based on structural similarity of representations.

In studying the phenomenon of design we use models (metaphors) to envision mechanisms by which computers might support design. One such mechanism is variously called search, exploration, discovery (and other terms)-under any name it is a guided movement through a space of possibilities. Design space explorers are computer media that engage designers in exploration. With them, designers explore possibilities. This encompasses discovering new designs, as well as recalling, comparing, and adapting existing designs. In creating design space explorers we represent the possibilities in the form of symbol structures called states and seek efficient representations for these states and algorithms over them. We represent spaces of possibilities as a relation over states and seek definitions of the space-generating relation which are both relevant to the exploration metaphor and lend themselves to tractable computations.

The aim of the SEED project (Flemming and Woodbury, 1995; Akin et al., 1997; Woodbury and Chang, 1995) is a comprehensive design space explorer exhibiting the above properties. SEED is targeted at the early phases of building design, where it is intended to encourage an exploratory design process by significantly shortening the time taken to generate and evaluate alternative designs. A common knowledge-level representation structures each of the main modules of SEED, which in turn further develop that representation in their own contexts. This knowledge level stands as a hypothesis of a complete, if abstract, description of SEED-Config as experienced by its users. It makes no commitments to its implementation, which might be realised in a number of different ways. This paper sketches *typed feature structures* as a formal system in which this knowledge level might be realised. Typed feature structures provide firstly formal properties useful to the knowledge level behaviour of SEED-Config, and secondly a mechanism for expressing knowledge level concepts.

Typed feature structures make the presumption, common but by no means universal, in the design literature (Newsome et al., 1989; March, 1995) that the entities of interest can be structured into a composition of objects and features. Thus representations such as shapes (Stiny, 1980) in which a definite representation comprises an indefinite set of parts would seem, at first glance, to be excluded from the typed feature structures game.

From the SEED-Config experience using typed feature structures, it turns out that the requirements posed on a representation for design space exploration are akin to those of evaluation in general. The strong relation between function and form, the ability to compare representations meaningfully and representation re-use are all crucial to evaluating designs.

A deep understanding of typed feature structures requires an appreciation of its formal mechanics, which, at least in the first author's experience takes fair effort to acquire. In this paper we give one sketch of typed feature structures emphasising their behaviour as a representation for a the evaluation aspects of a generative design system. Woodbury et al.(Woodbury et al., 1999) gives a more detailed account of how typed feature structures model design space exploration and Carpenter(Carpenter, 1992) provides the definitive description of typed feature structures, including many proofs for those readers wishing to tackle the formalism in full gory detail.

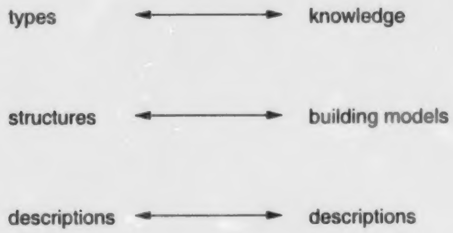

Fig. 1: Abstract elements of a typed feature structure representation

2 Typed feature structures as a representation

As a first approximation, consider a system made out of three sets of components: types T, structures *F* and descriptions *D*, put into a representation scheme with a building design domain as shown in Figure 1. The types comprising T stand for expressed knowledge of the domain of interest, in this case building design. Structures from *F* represent models of particular designs, in this case, buildings and/or their components, either physical or conceptual. Structures from *F* are expressed in terms of the information expressed in T. Descriptions from *D* are utterances in a formal textual language and stand for themselves in the representation scheme, but correspond symbolically and *inter alia* to sets of structures from *F*. The essential act of generation corresponds to the discovery of models of buildings that are simultaneously compatible with a description and the knowledge from the domain of interest-in typed feature structure terminology generation is the computation of structures compatible with a given set of types and a given description. All of this is ordinary in the realm of current knowledge based system theory and can be found, in many variations, in the literature. In the sequel we describe aspects that typed feature structures provide to a generative system. For now, as much as possible, we eschew the abstract symbolic terms of type, structure and description, relying instead on their domain counterparts, namely knowledge, model and description.

We use, as an example, a house type, common in Australia, known as a single-fronted cottage. Single-fronted cottages are simple houses, comprising a single-loaded hallway, rooms off of the hallway and a collection of spaces at the end of the hallway. The rooms along the hallway are typically generic in function and can be used as bedrooms, lounges, dining spaces, studies, etc. he hallway and its adjacent rooms are typically housed under a single roof, which is either a gable or a hip. The collection of rooms at the end of the hallway is typically configured as a skillion (space under a shed roof addition) or historically as separate structures (typically a kitchen and toilet). A porch along the front of the cottage completes the typical picture. Single-fronted cottages are a historic housing type, filling a niche of small, mostly inexpensive housing. Latterly many have been upgraded with particular attention being given to elaborations of the skillion addition, usually into a combination family room, dining room and kitchen. New houses in the single-fronted genre are still being constructed in inner suburban areas.

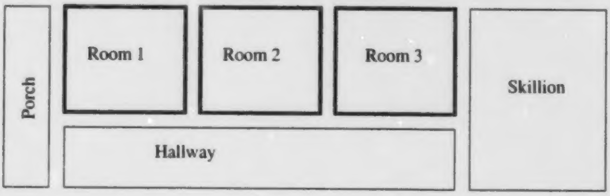

Fig. 2: Rooms 1, 2 and 3 can be identical in all aspects yet remain distinct

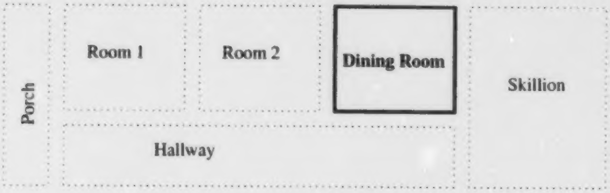

Fig. 3: The dining room and its location is all that is known

2.1 Structures are both intensional and partial

Intensionality in a representation scheme means that two symbol structures can be identical in all aspects yet remain distinct. In an intensional representation actual identity of two structures must be explicitly called out, for example, by a declaration that two compatible structures are, in fact, one and the same. From a domain point of view, we wish to be able to distinguish between models that differ only by the fact of their separate existences. As shown in Figure 2, in our example realm of single-fronted cottages, the three rooms of the room row can be identical in all aspects, yet remain distinct.

Partialness means that a structure need not contain all information that might be inferred about it from its associated types. In effect, a partial representation A stands for all more complete representations which contain at least the information in A. Appealing to a domain perspective, a model may contain less information than we can infer from our knowledge of it. Figure 3 shows that a model of single-fronted cottage with its dining room in the room row can exist without holding any other information on single-fronted cottages.

Partialness and intensionality swim together. We can know very little of two structures, except that they are different-or that they are exactly the same structure. In terms of cottages, a we may know that the dining room is or is not the third room in the row. Conversely, within a computation, a given structure is not necessarily the same as another that contains consistent information, but might be made so at some future point in the computation. For example, Figure 4 shows that two separate cottage models may at some point become a single composite model, containing all information from both. In this figure and in all figures demonstrating information inclusion we depart from the normal convention in artificial intelligence of drawing specialisation relations with the most general concepts at the top. We do this for two reasons: (1) to cohere with the intuition that a structure containing more information than another is somehow "greater" than the other, and (2) the typed feature structures literature follows this convention.

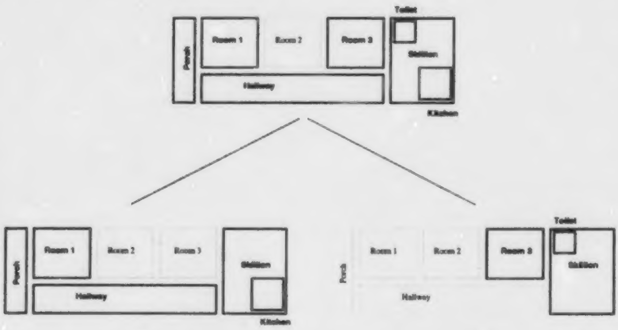

Fig. 4: Two cottage models that are consistent yet incomplete, can be joined into a single cottage model containing the information from both models

2.2 Partiallness is in the eye of the beholder

Whether a structure is partial or not depends on the content of its associated types. In domain terms a model might be partial against one set of knowledge but complete with respect to a subset of the knowledge. For example, if knowledge of single-fronted cottages is limited to their spatial organization, as might be the case for an urban geographer, a complete model of a cottage would assign functions to physical spaces. Such a model would be partial with respect to a larger set of knowledge, containing, for example, knowledge of how to construct single-fronted cottages. In terms of generative systems, partialness in a model indicates that more exploration is possible from that model. Conversely, adding new knowledge opens up new exploration possibilities for previously completed models.

In the domain of single-fronted cottages, Figure 5 shows that a cottage about which we know only the location of the dining-room is consistent with alternatives for the placement of other rooms. If our knowledge of the building type consists of only spatial organization, a model is complete once we have allocated all functions to specific rooms.

2.3 A generative system without rules

Recall that our formal system comprises three sets: types T, structures *F* and descriptions *D*, with elements of *D* standing for subsets of *F*. Further, imagine, firstly that there is a relation of satisfication *M* linking the structures from *F* that are consistent with a given description, secondly that there is an efficient procedure P for computing *M*, and thirdly that a type from T itself has a corresponding description in *D*. Then the same procedure that generates structures consistent with a description can generate structures consistent with the set of types. In effect, the type hierarchy itself becomes what Carlson describes as a design space description mechanism(Carlson, 1994). In domain terms, from knowledge we can infer designs.

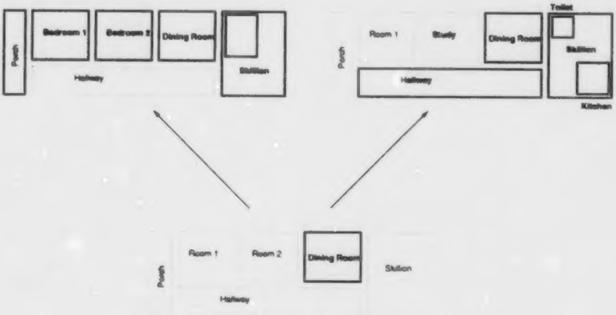

Fig. 5: A partial model of a single-fronted cottage is consistent with multiple complete models

2.4 Monotonic generation

The fact of partial structures provides, in itself, a notion of what might comprise generation, namely the alternative completions of partial structures into more specific partial structures and finally to complete structures. This amounts to a claim that the generating procedure P must act incrementally, i.e., it must progressively generate more and more complete structures as it works through its input description. P thus stands as the design space generator in this scheme-by its action it traces out a derivation relation from state to state. Under such a regime, generation is monotonic with respect to the structures it creates. In other words, if a fact is known in a model, it remains known in all models that can be created from that model. It is well-known that monotonicity is a double-edged sword. While it enables search strategies based on branch-and-cut, it restricts the set of allowable operators and possible derivation sequences.

Appealing to our example domain, Figure 6 shows that a partial model of a single fronted cottage in consistent with multiple models, both partial and complete, and these models are related by the action of the procedure that generates one from the other. In this example, we are clearly recovering part of the subset relation over the set of rooms in the single-fronted cottage-general structures are more complex.

2.5 Design spaces are structured by subsumption

Monotonic generation implies that the derivation relation is a subsumption relation, i.e., an model B derived from an model A contains strictly more information than A. With respect to single fronted cottages, Figure 6 shows that, in any derivation chain of models, each model contains strictly more information than its predecessor.
Derivation defines only a subset of the full subsumption relation. If we presume an efficient way of comparing structures from F for their information specificity, i.e., for the subsumption relation, then the full subsumption relation for a set of discovered structures can be recovered in the process of generation. Further, if structures are thought of as themselves comprising structures this subsumption relation can be recovered for all the parts of a structure.

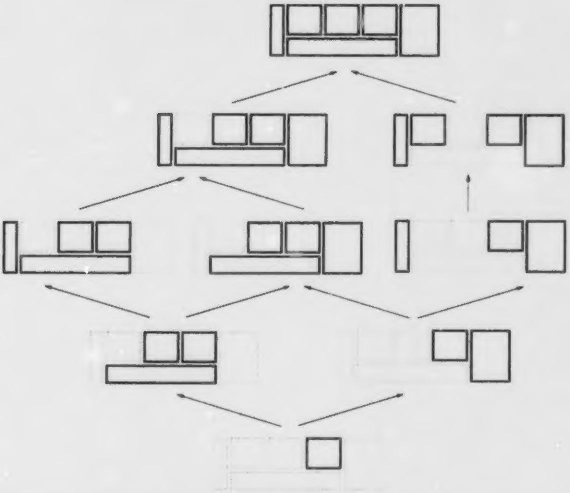

Fig. 6: From a partial model of a single-fronted cottage can be generated a graph of consistent partial and complete models

Having access to the full subsumption relation in a design space enables forms of exploration richer than *branch-and-backtrack* usual in generative systems. The branch aspect of generation remains largely unchanged. Backtracking becomes more rich, in that the derivation relation along which backtracking typically takes place is replaced by the full subsumption relation-from a given state, it is possible to move to less specific designs that have previously been discovered and to less specific designs for parts, irrespective of the process by which the designs were generated.

2.6 Re-use and evaluation-by-structure are intrinsic

The aspirations of design space exploration trade heavily on an ability to re-use information already discovered, for example, to find and adapt for the present single fronted design that clever island-feature kitchen design someone in your firm did in the Darwin office sometime in the last two years.

Together, partialness and the subsumption ordering over structures provide a seductive view on re-use of designs, the required actions for which are retrieval and adaptation. Recall that a structure is a partial specification of an object, that it is consistent with all objects that contain at least the information specified in it, and that structures exist in a subsumption ordering. It follows that any structure effectively indexes those structures more specific than it in the subsumption ordering-the same mechanism by which designs are represented can be used for retrieval. Once retrieved, the design space explorer operations (monotonic generation, enriched backtracking and information removal) are available to adapt the design to a new context.

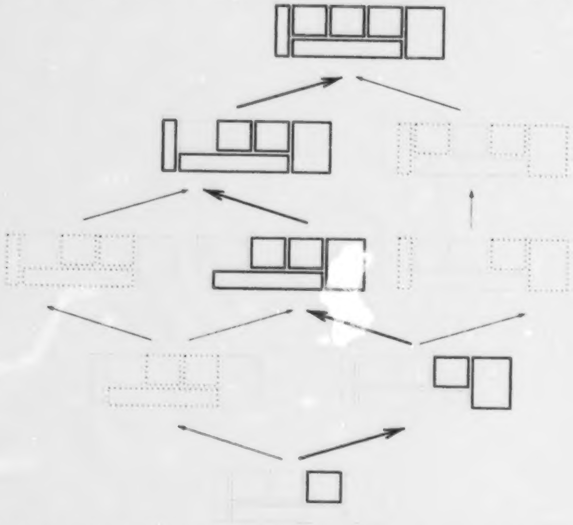

Fig. 7: The derivation relation is a subset of the full subsumption relation over models

In their support of re-use, typed feature structures would appear to do some of the duties of a case-based design system, for which the required mechanisms are representation, indexing, retrieval and adaptation. In the typed feature structures view, both cases and their indexes are indistinguishable from a structure, case retrieval indistinguishable from navigation in a subsumption relation of designs and case adaptation indistinguishable from design space exploration.

If we consider a case index as a structure, then indexes, like structures, have their own place in the subsumption relation of structures. More specific structures are instances of the case; less specific structures are a form of partial match of the case. This view on cases corresponds to the two kinds of matches that Flemming describes for cases in the SEED system(Flemming, 1994). Given the availability of the subsumption relation over structures and their parts, the index vocabulary problem described by Kolodner(Kolodner, 1993, Chapter 6) would appear to disappear-the index vocabulary is the full vocabulary from which structures are constructed and indexes are implicit in the subsumption ordering.

With respect to evaluation, this re-use ability means that exemplar designs demonstrating given properties, either in themselves or in their subparts, can directly compared to candidate designs to determine if the same properties hold. Further, the candidate designs can be extended without the chosen properties becoming invalid. Such an ability would appear to be a mechanism for certain types of evaluation, for example, compliance with deemed-to-comply provisions.

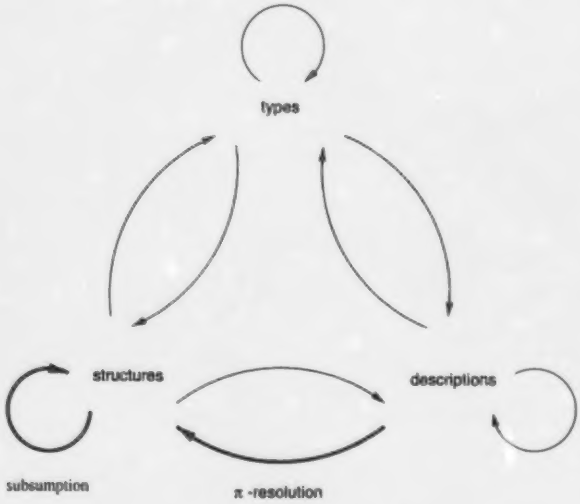

Fig. 8: Principal computation paths in typed feature structures

2.7 Summary

In the light of the above features, to the sketch of the typed feature structure representation scheme in Figure 8 can be added two principal relations corresponding to computational paths amongst its symbolic components as shown in Figure 8.

The generating procedure P (called π-resolution) that captures a relation from descriptions to structures $M : D \rightarrow F$ is the main exploration mechanism in the system.

Access to the subsumption relation $S : F \rightarrow F$ for structures and their parts provides a design space structure which includes the derivation relation as a subpart. Case indexing and retrieval are essentially search in the subsumption relation. An episode of design space exploration would employ both P and movement in the subsumption relation.

Several computation paths would appear to be excluded from the family of computations available in this scheme. Types especially seems to be estranged. A more complete, and technical, presentation of the typed feature structures formalism would show that a description can call out a type, thus bringing types back into the fold. Most other paths have corresponding well-formed relations, but these are subsidiary in design space exploration and in design evaluation.

Typed feature structures are a model for design space exploration in which both the action of exploration and the structure of a design space are given a sound theoretical basis. As a representation of designs, typed feature structures provide well-founded support for an object-and-relations view of representation and within that view support intensionality, partialness, monontonic generation, re-use and evaluation by structural comparison.

3 Acknowledgements

The authors would like to acknowledge the support given by the Australian Research Council Large Grants Scheme, The Department of Industry, Science and Tourism Major Grant Scheme, the Australian Postgraduate Award Scheme, The Commonwealth of Australia Overseas Postgraduate Research Scholarship Scheme, The Key Centre for the Social Applications of Geographic Information Systems and The University of Adelaide School of Architecture, Landscape Architecture and Urban Design.

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254 IMPROVING THE BRIEF THROUGH INFORMATION AND PROCESS MODELLING

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Abstract

Due to the vast amount of information and knowledge involved in construction projects, clients often have difficulties in identifying and communicating their actual requirements. In order to address this information effectively during the briefing process, such information is modelled into structured data models using EXPRESS-G technique. The processes involved during the development of the brief, however, are modelled using IDEF0 technique.

The developed models establish the foundation for the development of a computerised system, which utilise an object oriented environment. The implemented object oriented data models then form the framework for the presentation of the client's brief. These models, when implemented into the computerised environment, will significantly enhance the communication channel between the various parties involved from a very early stage of a construction project. The outcome is an improved brief, which fulfils the client's budgetary constraints.

Keywords: Brief, briefing process, computerised environment, information modelling and process modelling

1 Introduction

1.1 Background

Previous studies conducted by Graham (1983), Hudson *et al* (1991), Barrett and Stanley (1996), Barrett *et al* (1996), and others suggests that the client's brief is often inadequate, poor or not sufficiently explicit. Furthermore, it may not truly reflect the client's requirements. This may be due to a lack of experience on the part of the client with respect to construction projects, or his inability to identify

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and convey his actual needs accurately to the project team. Another contributory factor could be the lack of mutual understanding or trust, and common objectives between the parties involved. Most crucial, however, is the immense magnitude of project information that needs to be considered during the briefing process.

The situation can be improved by encouraging clients to participate fully or to a greater extent during the briefing process. This can be achieved by increasing the client's level of awareness through effective presentation and manipulation of the project information and the associated processes. The client's knowledge of the entire briefing process can then be enhanced considerably. Clients and other project participants can then work together harmoniously, both to identify a clear range of opportunities available for the development and to highlight any possible problems, which require a solution (Gray *et al* 1994). Through such discussions, a closer rapport between the parties involved will be established. This will lead to an increase in understanding and sympathy for each other's objectives. On this basis, it is presumed that the communication channel between the client and other projects participants, in particular the designer, can be improved significantly. This will ultimately pave a way towards better briefs to support the clients' requirements.

1.2 The brief

The *brief* documents the client's perceived needs and requirements and the feasibility of the proposed venture within overall budgetary constraints. The brief can be expressed as a definitive written statement prepared during the briefing process, which sets out the client's requirements for a construction project. It specifies at any point in time the relevant needs and aims, the resources of the client and user, the context of the project, and any appropriate design requirements within which all subsequent briefing and designing can take place (BSI 1995).

1.3 The briefing process

The *briefing process* refers to either:

a) A stage or stages in the design or construction process, or as part of the overall life cycle of the project.

b) A systematic method of enquiry by which client's requirements are made explicit. It is the process of eliciting or "brief-taking" (Barrett and Stanley 1996) the information or requirements from clients. Briefing is defined by the British Standards Institution (1995), as a process of identifying and analysing the needs, aims and constraints (the resources and the context) of the client and the relevant parties, and formulating any problems that the designer is required to solve. The briefing process, thus, involves the gathering, organising, analysing, identifying, interpreting, compiling, and documenting or presenting all the essential information required for a construction project.

This paper adopts the second reference of the *briefing process* and considers the *brief* as the output of the briefing process.

2 Sources of information

A set of relevant documents, which support the briefing process and/or contains recommendations on the constituents of the brief has been examined. Such documents include O'Reilly (1987), Duerk (1993), BCO (1994), Gray *et al* (1994) and BSI (1995). From the analysis, the majority of the selected publications were found to contain valuable and vital information for the formulation of the brief. However, none of the sources was found to be flexible enough to allow information to be articulated precisely enough to facilitate the process of information modelling. As such, more than one source of information or publication is necessary.

Useful and relevant information were extracted from the selected publications with the aim of reproducing a set of information which not only represents that essential for inclusion in the brief, but is also flexible enough to be modelled. A structured framework for the presentation of the brief is established, which will also aid the process of information modelling. The framework contains robust information that is common to most of the reviewed guidelines, which demonstrate the client's genuine requirements.

The structured framework is divided into five main sections: 'Project Identification', 'Project Aims', 'Project Resources', 'Project Context' and 'Design and Performance Requirements'. The titles of these main sections have been adapted from the selected publications. Each section reflects its own individuality that will allow a more flexible and manageable approach to the process of modelling the information. Further more, the identity of each section will be better defined in terms of assisting clients to distinguish and identify the needs and requirements of a project. Table 1 depicts the structured framework of the brief presentation

Table 1: Structured framework of the brief presentation

Project identification • Project identity • Project purpose • Project scope • Identity of project participant organisations • Identity of related group organisations **Project Aims** • Intended effects of the project	**Project Resources** • Financial • Time • Project management **Project Context** • Intended occupancy in detail • Regulatory issues • Background and historical influences • Site and surrounding influences • Client's future enterprise	**Design and performance requirements** • Site and surroundings • The building as a whole • Building fabric • Spaces in detail • Grouping of spaces • Plant, equipment and furnishings

3 Information modelling

The EXPRESS-G modelling technique (Schenck and Wilson 1994) has been adopted for the purpose of modelling the entities, which correspond to the contents of the brief along with their attributes and relationships.

3.1 Context diagram

Figure 1 portrays a framework for the brief presentation. It illustrates that the brief, represented by the 'Brief' entity, is a statement, which describes a construction project. The project, being represented by the 'Project' entity, has specific relationships with the main entities; namely 'Project Identification', 'Project Resources', 'Project Aims', 'Project Context' and 'Design and Performance Requirements'. These five entities represent the information essential for inclusion in the brief, and correspond to the five main sections of the structured framework shown in Table 1.

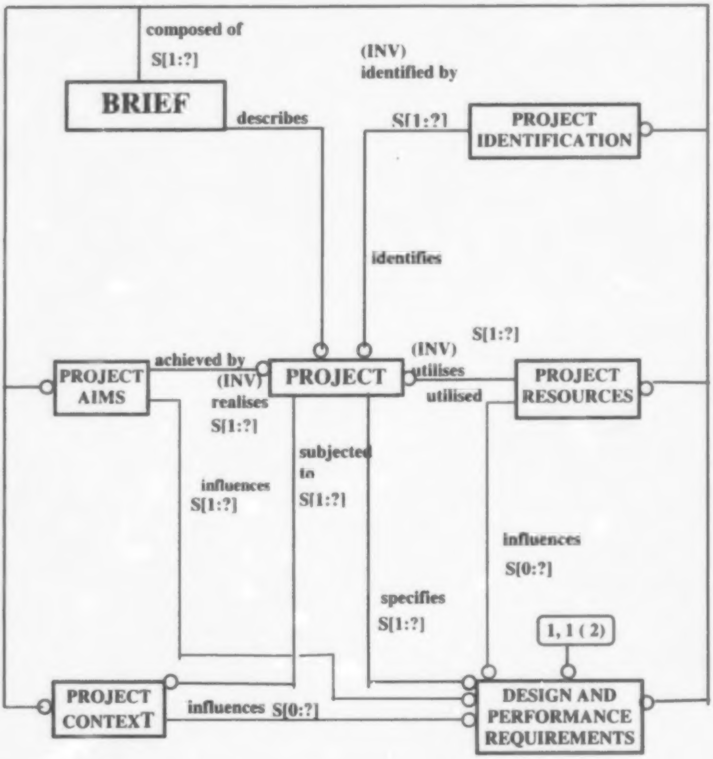

Fig. 1: Framework for the brief presentation (EXPRESS-G diagram 1 of 3)

3.2 Lower level diagrams

The information modelling process proceeds by decomposing the context diagram into lower level diagrams. This involves breaking down the entities by sub classifying them into their subtypes or relationships with other entities. A level 1 and a level 2 diagrams are portrayed in this paper to illustrate the modelling concept.

Figure 2 depicts the subtypes of the 'Design and Performance Requirements' and the entities linked to it. Figure 3 illustrates the entities and attributes linked to the 'Building as a Whole' subtype depicted in Figure 2.

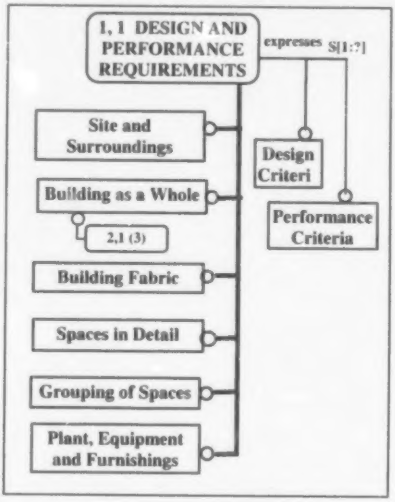

Fig. 2: The 'Design and performance requirements' entity (EXPRESS-G diagram 2 of 3)

4 Process modelling

For the purpose of modelling the brief development process, the IDEF0 modelling technique (Ross and Schoman 1977; Ross 1977; Sanvido 1990) has been adopted. A top down approach has been conducted where high level processes are modelled first, followed by low level decomposition of the relevant activities. IDEF0 diagrams have the extra edge of not only portraying the main activities involved during the development of the brief, but also identifying the data constraints between these activities in the form of inputs and outputs, the controls and the mechanisms required to carry out these activities.

The activities have been identified within the context of the development of the prototype computer environment with respect to two viewpoints. These include the system architecture of the prototype, and the information to be acquired at every stage of the development of the brief to suit the structured framework of the brief presentation.

4.1 Context diagram

Figure 4 shows the A-0 diagram for 'Develop Brief'. This is the topmost level of the IDEF0 diagrams. The 'Client Requirements' and the 'Construction Industry Know-how' represent the input. 'Client's Requirements' refer to all the

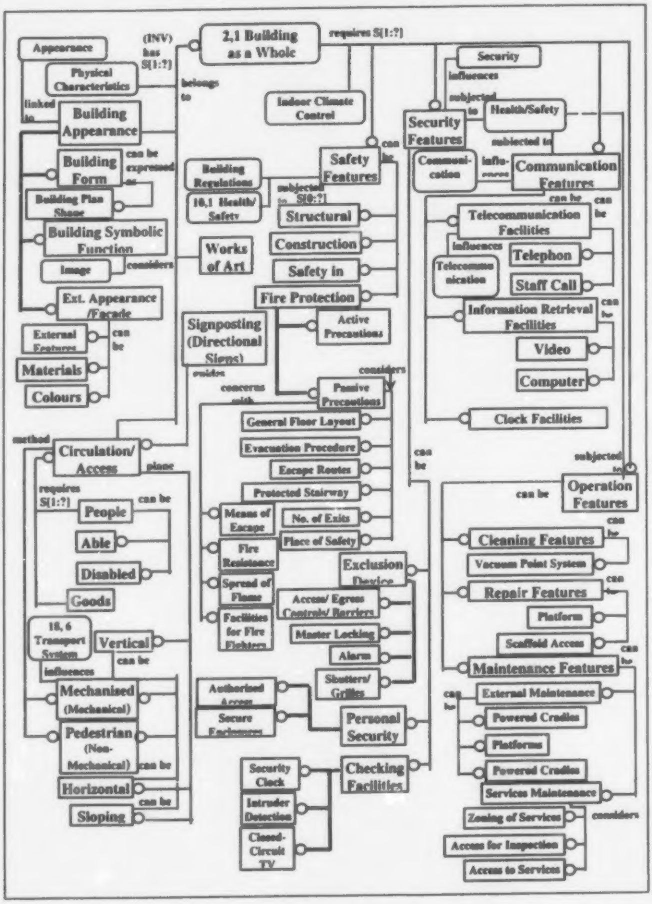

Fig. 3: The 'Building as a whole' subtype (EXPRESS-G diagram 3 of 3)

needs and requirements of the client with respect to the project while 'Construction Industry Know-how' refers to project related information (supporting information) available within the construction industry. The controls consist of the 'Brief Domain', the 'Data Models' used to build up the knowledge representation within the prototype, and any 'Technology Limitation' associated with the mechanisms used, such as the 'Software Applications' and the 'Multimedia Tools'. The client, any member of the design team, or others, may represent the third mechanism, the 'User'. Finally, the output of the process, is the 'Brief' that can be presented in various forms.

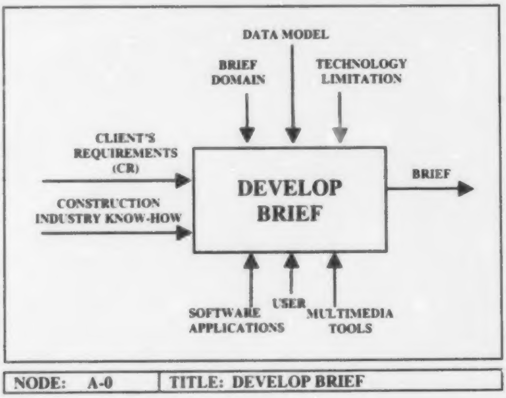

Fig. 4: A-0 diagram for 'Develop Brief' process

4.2 Lower level diagrams

Further decomposition of the 'Develop Brief' process have been carried out based on the two stated viewpoints until the achieved level of detail is considered sufficient for the application of the model for the prototype development. The level 1 diagram for the system architecture viewpoint is shown in Figure 5 .

The level 1 diagram for the information viewpoint, on the other hand, models the activities associated with the overall compilation of information for the brief development. Further diagrams at lower levels of abstractions are then produced (the diagrams are not shown in this paper). This aims to illustrate the related sub-processes further down the hierarchy and to visualise the actual flow of information at every stage of decomposition. This is an essential procedure which serves to establish the kind of information that needs to be presented to the client and indicates how and from where this information can be obtained quickly and efficiently.

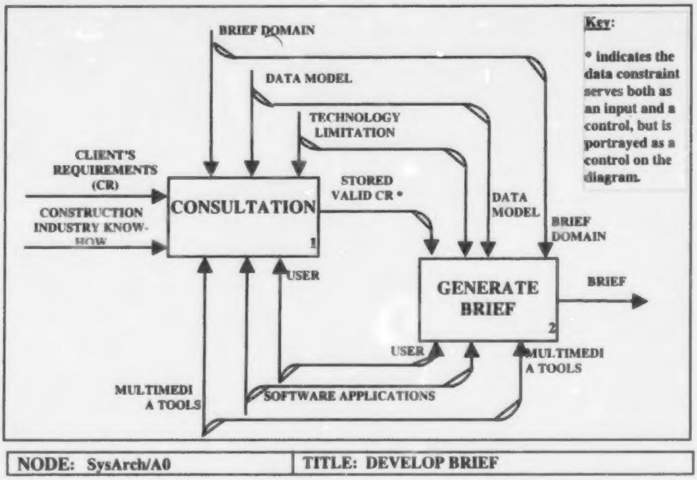

Fig. 5: SysArch/A0 diagram for 'Develop Brief' (System architecture viewpoint)

5 The implemented computerised environment

The models developed above play an important role in establishing a conceptual model for a computerised system since they can be mapped directly onto an object oriented environment with multimedia support. In such an environment, information can be manipulated and presented to users in a timely and effective manner. Such a system can operate as an intelligent mechanism for capturing the client's requirements, interpreting them, retrieving and presenting the necessary information required for the decision making process. A system architecture for the developed computer prototype is depicted in Figure 6. The system architecture comprises the Core Engine, the Interface and the External Resources.

The Core Engine which is an object oriented development environment, contains all the necessary information which is required by the brief, as represented by the developed data models. Using the EXPRESS-G data models, entities and their subtypes will represent objects within the object oriented environment while their attributes will be represented either by the attributes of the data model or their attributes' subtypes. The relation between the various aspects of the brief's data will be drawn from the data models, as represented by the relationships between the entities. On the other hand, the developed process models will provide the necessary procedures that are required by the system. By incorporating the data models with the process models, the total behaviour of the system can be defined. The external response to user requirements can be monitored and controlled intelligently by the data models, while the internal reaction to the various input criteria can be dictated by methods/production rules attached to the objects.

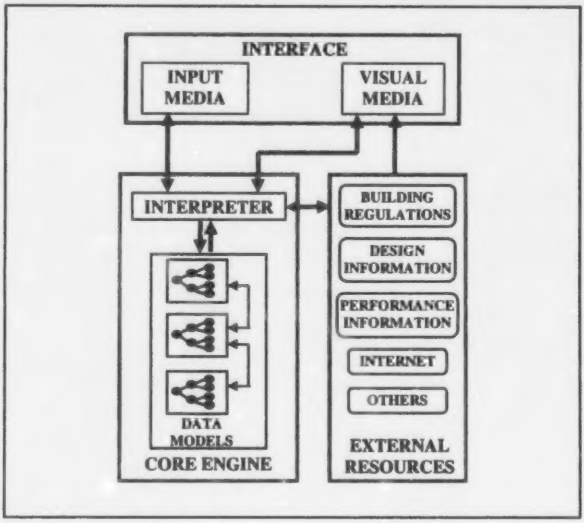

Fig. 6: System architecture for the computerised environment

The internal behaviour of the system is vital to the briefing process because of the diversity of the briefing process and the related information. For example, when the data models are supplied with project information, say the design criteria, the attribute values of each 'Design Criteria' will be checked to ensure its compatibility with the relevant 'Performance Criteria' attribute and vice versa. So, if a curtain wall is selected for a specific design criteria, the system will automatically ensure that this solution will not conflict with previously defined performance criteria such as maintenance and energy loss. Not only will this allow the relations between various entities of the brief to be easily controlled and monitored during the briefing process but it will also have a significant impact on maintaining consistency and accuracy between the various parts of the brief.

Multimedia technology (Burger 1993; Luther 1994; Bunzel and Morris, 1994) is used to control the way in which information is displayed in the Visual Media part of the Interface, which serves as the second component of the system architecture. Video clips, images, sound, and so on, can support objects in the data model, which are accessed as and when required. If, for example, the Core Engine recognises a specific data input as a request for presenting other information which is required for the decision making process, the necessary functions will be triggered within the Core Engine. This results in the retrieval of the required information. This information will then be displayed in the appropriate media through the Visual Media. These processes may interrogate internal and/or external resources such as databases as well as accessing on-line services or the Internet, thus allowing users to retrieve up-to-date information during the briefing process. This presentation of information not only increases the users' knowledge and level of awareness but also improves the users' understanding which, in turn, has an impact on the decision making process.

6 Discussion and conclusions

This study has modelled the vast amount of information essential for the development of the client's brief. Information has been classified and the relationships between various entities established. The main processes involved in the development of the brief have also been identified and modelled. The data and process models have then been used to establish the system architecture for a computerised environment to support the briefing process. Multimedia technology is utilised for the presentation of project information, thereby serving as an effective means of communication between clients and designers. Thus, the data and the process models, together with the prototype development, create a situation that serves to overcome the deficiencies of existing briefs by producing a comprehensive brief that reflects the client requirements.

Through more individual input and participation on the part of the client, and by being able to acknowledge and visualise the essential information required for a project, the client's understanding can be improved. The client will be able to identify and convey his or her true requirements in a more effective manner. This enables the designer to interpret the requirements effectively in the form of a well-defined brief, which will provide the basis of an appropriate design solution. Value for money can be attained in the form of a design solution that satisfies the client's requirements within the budgetary constraints.

In conclusion this research makes a significant contribution to the construction industry by combining data and process modelling to establish the platform for a computerised environment as a means for improving the brief. The system architecture implemented into the prototype enables it to provide on-the-spot advice, consultancy and visualisation of project information to clients or other users during the briefing process. The prototype can also be considered as a comprehensive and an intelligent front end to commercially available CD ROM products. With more refined testing and further development, it not only has the potential to serve as an essential part of the briefing process, but would also widen the market for these products to cover clients, designers, and other construction professionals who might be involved in any aspect of the brief. This could narrow the gap between clients and designers, thereby eventually improving the effectiveness of the communication channel between them. Moreover, the computerised system would also ensure consistency in the interpretation of the brief amongst construction professionals. The improved brief will play a major role in facilitating the entire briefing process, which will ultimately lead the way towards greater client satisfaction.

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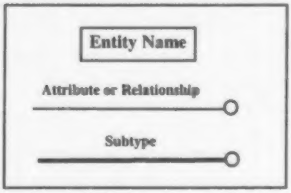
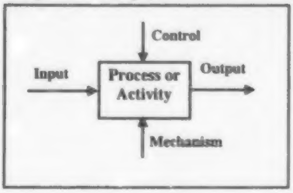
Yusuf, F. (1998), Modelling of Information and Processes for IT Implementation at the Brief Development Stage, Second International Conference on Construction Project Management, Critical Issues and Challenges for the Next Millenium, February 1998, Singapore, pp. 334-342.

Appendix A

Legend for Figures 1, 2 and 3:



Legend for Figures 4 and 5:



PART NINETEEN

LIFE CYCLE MODELS AND FACILITIES MANAGEMENT

255 COMPUTER SOFTWARE ARCHITECTURE TO SUPPORT AUTOMATED BUILDING DIAGNOSTICS

D.P. Chassin

Pacific Northwest National Laboratory, Richland, WA, USA

Abstract

Developed by Pacific Northwest National Laboratory's Building Sciences Group, Honeywell Technology Center, and the University of Colorado Joint Center for Energy Management with support from the U.S. Department of Energy, the Whole Building Diagnostician is a Windows-based application that provides building operators with easy access to system diagnostic information. The architecture of the software infrastructure presented provides essential data collection, validation, integration, analysis, and management functions for the large sets of discontinuous asynchronous time-series data used by all the modules in the application. The proposed architecture uses a central database to store both the data and the diagnostic results from the various modules. Although the use of a centralized database has many advantages, it has several shortcomings. This paper will discuss the advantages and shortcomings of such an approach when deployed on a large scale.

Keywords: building diagnostics, computer software, ventilation diagnostics

1 Introduction

The Whole Building Diagnostician (WBD) is a system created to provide building operators access to information about the performance of the buildings for which they are responsible. The first operational version of the WBD provides failure diagnostics for air handlers, and performance tracking at the whole building and the aggregate plant level, (Brambley et al. 1998).

[†] Pacific Northwest National Laboratory is operated by Battelle Memorial Institute for the US Department of Energy under contract DE-AC06-76RLO 1830.

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The WBD infrastructure provides the systems in support of the interaction between the various WBD modules. In general, it provides the following services as shown in Fig. 1:

- data transport and storage
- module execution and control
- installation and setup

2 System requirements, design, and implementation

2.1 Data collection

The WBD collects data from a variety of Building Automation Systems (BAS) using DDE, trend logs, or custom interfaces. (Some interfaces such as those for BACnet are planned but have not been implemented to date because of a lack of demand.) For each BAS, a driver must be designed and implemented. Data is then automatically collected from the BAS, processed and delivered to the diagnostician's data sources.

2.2 Data access

The user views and edits configurations, schedules (see Fig. 2), and views data and diagnoses during WBD session. Data pertaining to the following categories of information is delivered to all WBD modules from the data sources:

- building component hierarchy and connectivity,
- sensor channels, connectivity, and conditions (locations, errors, tolerances and biases),
- building, plant, air handler, zone, and BAS configurations,
- building, plant, air handler, zone, and data collection schedules,
- sensor readings
- diagnostic results and intermediate calculations
- energy rates and costs

Database transaction control and disaster recovery services are used to maintain database consistency in the event of a variety of system failures (e.g., power outage, hardware or software failure).

2.3 Database schema maintenance

The infrastructure provides database services to perform the following tasks:

- debug the implementation of all the diagnostic modules and the infrastructure itself,
- automatically upgrade the database schema to the most recent design,
- audit every data table for consistency with other tables, and
- repair damage resulting from crashes, power outages, and hardware failures.

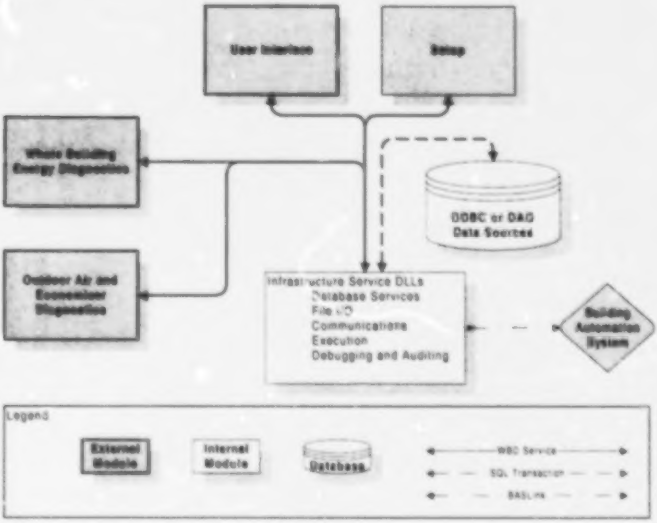


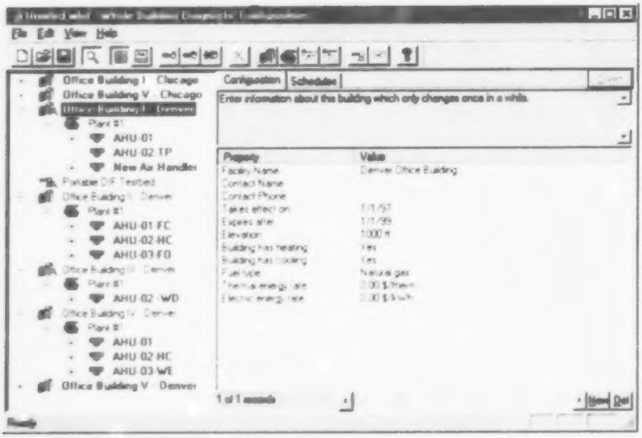
Fig. 1: Whole building diagnostician system structure

2.4 Process scheduling

The WBD controls execution of diagnostic modules and specifies the analysis desired by the user. Users may instruct each diagnostician individually to start either when the system boots up, when user logs in, when a WBD session is opened, or never start at all. In addition, users may individually instruct each diagnostician to shut down either when the system shuts down, when the user logs out, or when a WBD session ends.

The processing schedule is determined based on which building components the user elects to monitor. The schedule is then dispatched to the appropriate diagnosticians which will perform the required operations to ensure the user receives the desired results.

When a fatal processing exception is encountered during analysis, the subject analysis is abandoned while other analyses are completed. After all the other analyses have been given an opportunity to complete, the subject analysis is restarted in an attempt to overcome the problem. If the processing problem persist, it may require user intervention. The user is signaled in the appropriate WBD session by indicating an exclamation point beside the appropriate component's icon.



Enter information about the building which only changes once in a while.

Property	Value
Facility Name	Denver Office Building
Contact Name	
Contact Phone	
Takes effect on	1/1/97
Expires after	1/1/99
Elevation	1000 ft
Building has heating	Yes
Building has cooling	Yes
Fuel type	Natural gas
Thermal energy rate	0.00 $/therm
Electric energy rate	0.00 $/kWh

Fig. 2: WBD building configuration screen

2.5 Building automatic system links

The WBD has been successfully linked to several buildings having Johnson Control's (JCI) Metasys system and one having a CSI automation system. At the time of this writing, construction of links to a number of the other systems is in progress or anticipated, but results from these are currently unavailable.

The JCI linkage was established using the Microsoft Window's Dynamic Data Exchange (DDE) protocols support by the JCI Metalink module. The WBD implementation of DDE-based data collection allows the WBD system installer to link to most DDE-capable BASs, using an approach similar to that used when linking from Microsoft Excel, and without implementation of custom software.

The CSI linkage is done using the WBD's trend-log loader. Many legacy BASs do not support data interchange protocols and can only output trend logs or database files. The WBD is capable of reading Comma Separated Value (CSV) files, Data Interchange Format (DIF) files, and databases supporting Microsoft ODBC. These control systems typically output a summary of short-period data and the WBD collects and integrates that data whenever necessary.

The implementation of BACnet support in the WBD is not currently available but it is anticipated within the foreseeable future.

2.6 Time integration services

The WBD supports two types of data: hourly and irregular data. Hourly data is stored as an integrated value at the end of the hour (i.e., data stored at 2pm represents an integration of values from 1pm to 2pm). Irregular data is stored at the time the value becomes valid and remains in force until another value is obtained and stored.

Hourly data must be integrated by the data collection modules. Since most of the WBD's diagnostic analysis is performed on hourly data this presents a convenient efficiency for data storage and processing. In the cases where daily summaries are required, hourly values are integrated.

However, in some cases values changing in a sub-hourly time scale or at irregular intervals must be available to diagnostic module. In such cases integration is performed on arbitrary period data. The integration method and interval may be specified at run time. Summary information supported and statistics delivered are:

- integrated, averaged, accumulated, minimum, or maximum values
- count of samples used
- first and last time stamps of samples used
- root mean squared error and mean bias error (for the indicated degrees of freedom)

2.7 Units, errors and reliability, and psychrometrics

A number of statistical and thermodynamic utilities are provided to simplify implementation and ensure consistent usage across the diversity modules. These include unit conversion services, error and reliability propagation calculations, and psychrometric routines.

Unit conversion is based on universal constants. Any physical quantity is expressed as a function of six constants. They are:

c	speed of light (2.997925 x 10^8 m/s)
e	charge of an electron (1.602189246 x 10^{-19} Coulombs)
h	Planck's constant (6.62617636 x 10^{-24} J/Hz)
k	Boltzman's constant (1.38066244 x 10^{-13} J/K)
m	rest mass of an electron (9.10953447 x 10^{-31} kg)
	(All found in CRC Handbook of Chemistry and Physics 1980-81)
s	value of 1 kilogram of gold (1.233270 10^4 1990$/kg), (GIAGP 1997)

After converting these quantities to SI, any physical quantity can be computed using the equation:

$$Q = c^{\alpha} e^{\beta} h^{\gamma} k^{\delta} m^{\varepsilon} s^{\phi} \rho + \sigma$$

where:

α is the exponent to c,
β is the exponent to e,
γ is the exponent to h,
δ is the exponent to k,
ε is the exponent to m,
ϕ is the exponent to s,
ρ is a scalar, and
σ is a constant offset.

The scalar is used to adjust to specify non-SI units and to translate from one unit to another. The basic SI and currency units are calculated as follows.

1 meter = 4.121487×10^{1} h / mc, with a precision of 7 significant digits,
1 kilogram = $1.09775094 \times 10^{30}$ m, with a precision of 10 significant digits,
1 second = 1.235591×10^{10} h / mc^{2}, with a precision of 7 significant digits,
1 Ampere = 5.051397×10^{8} emc^{2}/h, with a precision of 7 significant digits,
1 K = 1.686358 mc^{2}/k, with a precision of 7 significant digits,
1 candela = 1.447328/683.0 $m^{2}c^{4}/h$, with a precision of 7 significant digits, and
1 US$ = 1.097751×10^{30} sm, in 1990 with a precision of 7 significant digits.

Mathematical computations are then greatly simplified since conversion between like units (i.e., the exponents to the constants are the same) is performed automatically by adjusting the scalar and constant offset and deriving new units by calculating new exponents from those of the old units.

Finally, all sensor readings are assigned limits, error boundaries, and reliability rates. If a value is outside the limits, it becomes invalid. Valid values have a lower and upper error boundary, and a reliability rate which indicates what percentage of the samples can be expected to have true values that fall between the lower and upper boundaries. In addition, all mathematical and boolean operations propagate the error boundaries and reliability rates. As a result, each diagnosis is given a reliability based on the reliability of the original sensor readings and the amount of arithmetic performed on those readings.

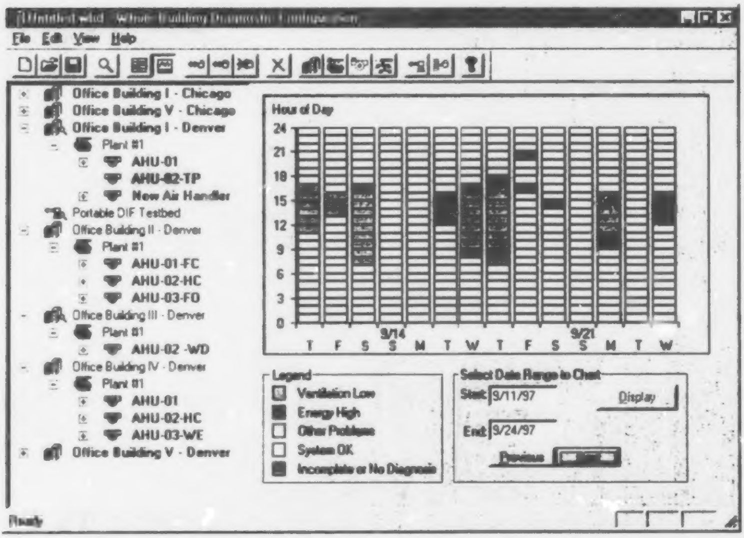
2.8 Text compression

All text is stored in the database using a tokenized compression algorithm. The system maintains a list of keywords used to compress commonly used phrases. As a result a message such as "The mixed air temperature is less than the return air temperature" is stored as "Tmix < Tret." This system is also used to maintain consistent terminology in all the many diagnostic messages, and to support rapid revisions to them. In addition, dynamic data retrieval is supported in order to allow the current values to be retrieved for a given message. Thus the message "ActualTmix is GetActualTret and ExpectedTmix is GetExpectedTmix." is translated to "The actual mixed air temperature is 68°F and the expected mixed air temperature is 72°F."

2.9 Outdoor air and economizer diagnostician

The Outdoor Air and Economizer (OAE) diagnostic module includes an instance of the system scheduler, the diagnostic processor, and the OAE user interface component. It provides state analysis and diagnostics for air handlers and economizers.

The scheduler reads the processing schedule dispatched by the user interface to the OAE module. Each building component that is to be monitored by the OAE is checked to see if any new data are available. As new data from the BAS are introduced in the database, the diagnostic processor handles these data.


File
Edit
View
Help
Office Building I - Chicago
Office Building V - Chicago
Office Building I - Denver
Plant #1
AHU-01
AHU-02-TP
New Air Handler
Portable DIF Testbed
Office Building II - Denver
Plant #1
AHU-01-FC
AHU-02-HC
AHU-03-FO
Office Building III - Denver
Plant #1
AHU-02 -WD
Office Building IV - Denver
Plant #1
AHU-01
AHU-02-HC
AHU-03-WE
Office Building V - Denver
Hour of Day
24
21
18
15
12
9
6
3
0
9/14
9/21
T F S S M T W T F S S M T W
Legend
Ventilation Low
Energy High
Other Problems
System OK
Incomplete or No Diagnosis
Select Date Range to Chart
Display
Previous
Ready

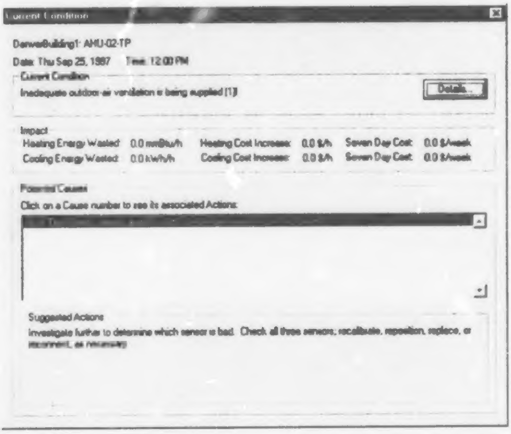
Start: 9/11/97

End: 9/24/97

Fig. 3: OAE state display

All new data are processed through the OAE module's state detection decision tree. As possible states are excluded using individual tests and calculation, the module records any impossible failures that can be inferred at that point. When an air handler's state is eventually determined, the OAE module records that state and any possible failures that can be inferred from that state. The module then processes the impossible and possible failures accumulated over recent hours and days in order to determine the most likely failure(s) that are consistent with that majority of reliable observations.

The OAE user interface (see Fig. 3) displays the diagnosis concluded for each hour based on the data obtained from the BAS. Users can drill down on each hour to obtain details on the system state and the diagnosis (see Fig. 4).



DenverBuilding1: AHU-02-TP

Date: Thu Sep 25, 1997 Time: 12:00 PM

Current Condition

Inadequate outdoor-air ventilation is being supplied [1]

Impact

Heating Energy Wasted: 0.0 mmBtu/h Heating Cost Increase: 0.0 $/h Seven Day Cost: 0.0 $/week

Cooling Energy Wasted: 0.0 kWh/h Cooling Cost Increase: 0.0 $/h Seven Day Cost: 0.0 $/week

Click on a Cause number to see its associated Actions:

Suggested Actions

Investigate further to determine which sensor is bad. Check all three sensors; recalibrate, reposition, replace, or reconnect, as necessary.

Fig. 4: OAE state details and diagnosis

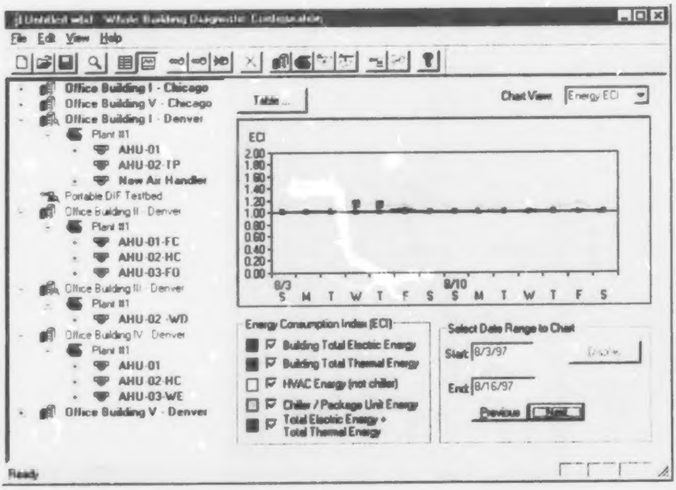

Untitled.wbd - Whole Building Diagnostic Configuration
File
Edit
View
Help
Office Building I - Chicago
Office Building V - Chicago
Office Building I - Denver
Plant #1
AHU-01
AHU-02-TP
New Air Handler
Portable DIF Testbed
Office Building II - Denver
Plant #1
AHU-01-FC
AHU-02-HC
AHU-03-FO
Office Building III - Denver
Plant #1
AHU-02 -WD
Office Building IV - Denver
Plant #1
AHU-01
AHU-02-HC
AHU-03-WE
Office Building V - Denver
Table ...
ECI
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
8/3
8/10
S M T W T F S S M T W T F S
Display
Previous
Next
Ready

Chart View: Energy ECI

Energy Consumption Index (ECI)

- ■ ☑ Building Total Electric Energy
- ■ ☑ Building Total Thermal Energy
- ☐ ☑ HVAC Energy (not chiller)
- ☐ ☑ Chiller / Package Unit Energy
- ■ ☑ Total Electric Energy + Total Thermal Energy

Select Date Range to Chart

Start: 8/3/97

End: 8/16/97

Fig. 5: WBE tracking screen

2.10 Whole building efficiency diagnostician

The Whole Building Efficiency (WBE) diagnostic module includes an instance of the same scheduler as the OAE module, but has its own efficiency tracking module and WBE user interface. The WBE provide Energy Consumption Index (ECI) calculations for whole building energy, whole building electric, whole building thermal, chiller and non-chiller energy usage. An ECI is the ratio of actual usage to expected usage. In addition the WBE is capable of detecting some power, gas, temperature and dew-point sensor failures.

The data processed through the WBE are used to calculate daily actual and expected ECIs. Any ECI with a statistically significant difference between the actual and expected value is flagged as a potential problem (see Fig. 5). The user can drill down on these days to obtain details on the severity of the problem and the anticipated cost impact.

2.11 Common user interface controls

The user interface module uses two common controls: the building component tree and the component configuration dialog. Both these controls are linked to the data sources and automatically maintain their synchronization to the data sources. In addition, the building component tree maintains the processing schedule information by displaying icons on the components to indicate active monitoring (the magnifying glass), a problem (an exclamation point--not shown), and the bolded component name (data and/or diagnosis available for viewing).

3 System performance evaluation

Database size is an important consideration when installing the WBD. In particular, large facilities or campuses must ensure that adequate storage is provided. The WBD collects and processes extremely large amounts of data. As the reader can observe in Table 1, building components with problems can be particularly burdensome to the storage facilities of the host computer. In general, the more complex or difficult the problem is to discern, the more storage is required to successfully diagnose the situation. This is especially true if multiple complex problems are present which are characterized by contradictory but simpler diagnoses. As a result, it is generally advisable to segregate a single large database into groups of smaller databases each with only a few components.

We have observed that processing speed is generally not a consideration when installing the WBD for continuous on-line operation. However, when batch operation is employed on a large number of buildings for long time periods, the delays in obtaining results can be considerable. For this reason, and for the sake of completeness, processing speed analysis was performed on a Pentium 166 MMX type computer running Windows 95. The results of this analysis are summarize in Table2.

Table 1: Database size statistics

Database Contents	Database Size (Megabytes)
Configuration data only	0.32
Whole building energy data only	1.5
Properly operating air handler data only	3.6
Improperly operating air handler data only	10.4

Table 2: Diagnostic Processing Speed Statistics

Processing Scope	Processing Time (seconds)
Diagnose 1 day of air handler data	7
Diagnose 1 day of whole building energy data with 3 months of baseline data	11
Diagnose 1 day of whole building energy data with 9 months of baseline data	31

4 The future of building diagnostics

An essential feature that we anticipate needing in future versions of the WBD is a linkage to simulations of physical components to provide a reference basis for model-based diagnosticians and for training baseline data needed by diagnosticians based on statistical or artificial intelligence methods. We anticipate that such simulation engines must meet a number of requirements that, at the current time, appear to be unsatisfied by the current generation of building simulation engines or those under development. First, simulations must be cost-effectively linked to diagnostic modules (either by integration or interoperability). Second, the simulation engine's data modeling requirements for diagnosticians are somewhat incompatible with the data that can be collected from building automation systems. Third, the simulation engines must be able to simulate a wide variety of realistic (i.e., commonly seen in the field) faulty behavior. As a result it is likely that the simulations must separate the component control scheme from physical behavior. Fourth, the simulations must be scalable. Thus, simulation engines that are given less data should provide more rough estimates of results, and the same ones when given more data provide more accurate estimates of results. Fifth, the simulation must provide comprehensive time-series reports of the interaction between the control system and the building components, reporting all sensor and actuator signals. Finally, these simulation engines must be capable of considering the uncertainty of some of the input data (e.g., occupancy, weather, sensor noise) when computing outputs such as energy use.

The International Alliance for Interoperability has been working on interoperability models called Industry Foundation Classes that will enable diagnosticians to obtain performance metrics from simulation tools in a more practical way than currently possible. However, the models to support the requirements suggested above have yet to be defined.

Tools such as the Facility Resource Energy Data (FRED) developed at Pacific Northwest National Laboratory collects, manages, and reports on large amounts of building energy usage data. The current installation of FRED at the DOE's Hanford Operations in Richland, Washington collects energy end-use data from about 90 buildings. Efforts are currently under way to integrate the WBD into this tool in order to enable tracking of building energy usage from within the FRED environment.

The data collection tools used by the WBD are not only capable of reading building automation system data, but they can send control overrides as well. While no current tools have been developed that exploit this capability, we anticipate developing diagnosticians which are capable of overriding control signals for short time periods in order to confirm diagnoses more quickly than is possible using the reasoning techniques already implemented in the WBD.

Continuous commissioning is another consequence of the ability to send control overrides from tools such as the WBD to the building automation system. In this approach, diagnosticians would periodically run building components through a series of exercises designed to demonstrate proper operations. In this way, a diagnostician would be capable of detecting a problem with a component (e.g., an economizer) before the component is needed.

5 Conclusions

The current field trials of the WBD have shown that system architecture is flexible enough to support a variety of building types and automation systems. These trials have also shown that the diagnosticians are effective in identifying installation and operation problems in air handling units in particular. Furthermore, the number of faulted air handling units found seems to support the conventional wisdom that the majority of economizers are experiencing problems due to installation, control, or maintenance failures.

The system architecture is designed to permit controls manufacturers to embed the diagnosticians within their control products. However, to date, no manufacturer has attempted this. We argue that by monitoring component performance proactively and continually, control systems will be able to ensure that equipment is more cost-effectively maintained, properly operated and with due diligence. In particular, we contend that the advent of tools such as the WBD will eliminate the excuse that is often used for failures to meet performance standards such as ASRHAE Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality*: that the tools to practically and continuously verify compliance are not available. While it is certain that the WBD does not assure indoor air quality any better than it might assure any other standard of performance is met, it does provide a first line of defense in doing so: that an adequate proportion of outdoor air is indeed being drawn in. Given a family of diagnostic tools developed in the coming years, we expect that more and more buildings will achieve the performance standards to which they were designed.

6 References

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256 INFORMATION ANALYSIS FOR ROOFING SYSTEMS MAINTENANCE MANAGEMENT INTEGRATED SYSTEM

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Abstract

The Building Envelope Life Cycle Asset Management (BELCAM) project, lead by the National Research Council Canada (NRCC) and Public Works and Government Service Canada (PWGSC), is a "proof of concept" project aimed at helping asset managers to predict the remaining service life of building envelope components and to maximize the return on their maintenance expenditure. The BELCAM project focuses on flat or low-slope conventional roofing systems as a representative domain. This paper focuses on maintenance management, which is primarily concerned with the management of all technical and administrative tasks involved in maintaining a building element in, or restoring it to, a state in which it can perform its intended function. A framework for the integration of the process of managing maintenance of roofing systems is proposed. The framework consists of five sequential steps: (1) Identification of roofing system components requiring assessment, (2) Identification of roofing system performance requirements, (3) Identification of performance assessment methods, (4) Roofing system maintenance planning, (5) Roofing system maintenance operations management. This paper introduces a framework for roofing systems maintenance management. It presents a preliminary analysis of an integrated information system to support maintenance management. The paper follows the development methodology adopted by the International Alliance for Interoperability (IAI) to represent the high-level information within the proposed framework of maintenance management. IAI projects follow a standard process-oriented development methodology, involving the following steps: usage scenarios, process definitions, information analysis and information modeling and validation.

Keywords: Maintenance management, roofing systems, performance requirements, condition assessment, planning, operations management, IAI, process analysis, product modeling

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1 Introduction

The Building Envelope Life Cycle Asset Management (BELCAM) project, lead by the National Research Council Canada (NRCC) and Public Works and Government Service Canada (PWGSC), is a "proof of concept" project aimed at helping asset managers to predict the remaining service life of building envelope components and to maximize the return on their maintenance expenditure. The BELCAM project focuses on low-slope conventional roofing systems as a representative domain. Some of the reasons justifying choosing this domain as an area for investigation include: roofing repairs are expensive and form a large portion of maintenance budgets; there is a considerable literature dealing with roofing durability; and it is a well-defined domain with some well-known links to other subsystems. The BELCAM project centers around six enabling technologies, namely; life cycle economics, service life prediction, user requirement models, risk analysis, product modeling and maintenance management. This paper focuses on one of the enabling technologies, namely maintenance management, which is primarily concerned with the management of all technical and administrative tasks involved in maintaining a building element in, or restoring it to, a state in which it can perform its intended function.

2 Proposed framework of maintenance management

The proposed framework for managing maintenance operations of roofing systems consists of fives sequential steps (processes). The framework starts with the current condition of a roofing system in hand, and ends with updating as-built records. Fig. 1 is a process flow diagram that illustrates the sequential flow of these steps. The following five subsections describe the proposed framework.

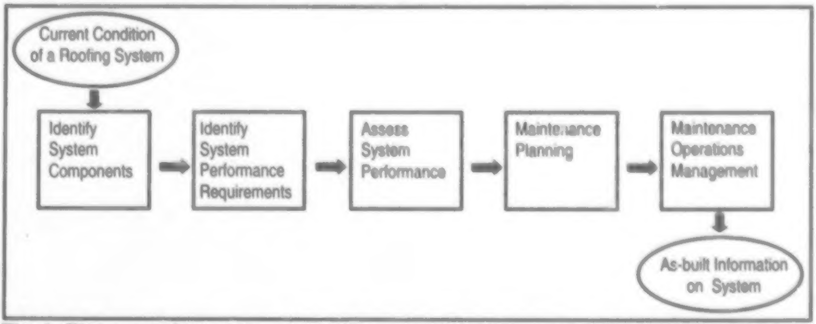
Current Condition of a Roofing System
Identify System Components
Identify System Performance Requirements
Assess System Performance
Maintenance Planning
Maintenance Operations Management
As-built Information on System

Fig. 1: Five general steps (processes) in proposed maintenance management framework

2.1 Identification of roofing system components requiring assessment

A typical flat or low-slope roofing system is comprised of a roof deck and supporting structure, vapor and/or air retarder, thermal insulation, roof covering, flashing materials, and top cover. There are two types of roofing systems, depending on the position of the insulation within the roofing system assembly. These are: exposed (conventional) membrane roofing systems, in which the insulation is below the roofing membrane, and protected (inverted) membrane roofing systems, where the insulation is above the roofing membrane. The BELCAM project is placing an emphasis on exposed roofing systems for which the roof covering material is single-ply, modified bitumen (mod-bit), and built-up roofing (BUR) membrane.

In the first regional survey (one of the BELCAM project deliverables) that took place in the Ottawa region in the summer of 1998, three main components within the roofing assembly were identified and targeted for visual inspection. These components are roofing membrane, flashing materials, and insulation.

2.2 Identification of roofing system performance requirements

Performance requirement is a statement of the needs to be fulfilled during the service life of a product (e.g. roofing system). Some of the efforts made to identify performance requirements of roofing systems include work by Booth (1987), Rissmiller (1981) and May (1984). Table 1 summarizes some these performance requirements along with their applicability to roofing system components and the associated evaluation technique. Griffin (1970) presented the performance requirements and their corresponding applicability to roofing systems' components along with the evaluation technique followed.

Table 1: Roofing system performance requirements (Griffin 1970)

Performance Requirement	Applicability				How Evaluated?
	Deck	Vapor Barrier	Insulation	Membrane	
Weather resistance				X	Test
Wind resistance	X	X	X	X	Test
Fire resistance	X	X	X	X	Test
Bitumen flow resistance				X	Test
Appearance				X	
1. Permanent deformation					Judgement
2. Surface defects					Judgement
3. Non-uniform color					Judgement
Thermal insulation			X		Test

Discussions with roofing experts and literature review indicated that carrying out tests for the purpose of evaluating roofing system performance is an expensive exercise and would normally only be carried out for problematic roofs. Since visual inspection is the most popular and economical means of condition assessment, and value judgment is widely employed as a way of evaluating performance requirement.

2.3 Identification performance assessment methods

There are two main categories of inspection techniques exist that are currently used in practice today:

External (visual) inspection: examination procedures from above the roof must be geared to the particular system and materials used in the roofing assembly. The BELCAM project is mainly concerned with the visual inspection of flashing and membrane of low-slope single-ply, modified bitumen and built-up roofs and determining their potential failure modes. The project is adopting the methodology of MicroRoofer (Bailey et al. 1989) for establishing procedures for consistent and objective measurements of roof baseline and condition assessment data, as well as for recording data on severity levels of each flashing and membrane distresses and defects.

Internal (empirical testing) inspection: while the roof may appear to be in good condition, there may be problems under the surface. Two categories of tests can be performed to inspect and determine the moisture content in an insulated roof system: Destructive Moisture Tests, including Roof Cuts Test (Dworkin 1990) and Moisture Meter Test (Monterose 1986); and Non-destructive Moisture Tests, including Infrared Thermography (IF), Nuclear Moisture Detection and Capacitance Radio Frequency Scanning (CRF) (Monterose 1986).

2.4 Roofing system maintenance planning

This step presents a method to recommend a specific management option based on analysis that encompasses and compares all relevant criteria throughout the life cycle of various roof management options. Alternative management options for roofing systems are:

1. **Maintenance**: includes general activities such as cleaning drains.
2. **Repair**: includes performing localized repairs to rectify situations of distresses such as repairing splits, holes and tears.
3. **Renewal**: includes installing a new assembly of roofing system either above the existing system, after disposing of the old roofing system.
4. **Do nothing**: includes postponing or ignoring maintenance, repair or renewal.

The selection of a waterproofing system for a building is one of the important decisions that an architect or a specifier make in a project. In some cases, the owner would prefer the system with the lowest initial cost due to budgetary constraints. However as indicated by Herbert (1989), many owners have found out the hard way that initial cost should not always be the determining factor in selecting a roof system. It can be argued that life cycle cost is the criterion that should be examined when recommending a specific maintenance management option. A conclusion can be made that the decision for the maintenance scenario for the waterproofing system is a process that depends on quantitative and qualitative judgment. The listing below presents four design decision variables or criteria that should be considered when deciding upon implementing a specific roofing system:

2.4.1 Performance and service life prediction

The BELCAM project is proposing the use of a probabilistic Markovian chain model to predict the performance of roofing membranes through modeling the deterioration and repair processes. The model accounts for time-dependence, uncertainty and variability of roof section performance (Lounis et al. 1998).

2.4.2 Life cycle costing (LCC) analysis

In addressing LCC implications of roofing decisions, literature indicates that one major difference between roofing decisions and other business investment decisions is that roofing investments rarely produce a revenue stream like other business investments. Roofing investments only produce a cost stream. Typical types of economic analysis decision-making criteria include: Net present value (NPV), Payback period, Savings to investment ration (SIR) and internal rate of return (IRR) (Doshi 1997).

2.4.3 Risk-based multi-objective decision analysis

The multi-objective optimization analysis is a procedure for decision making under conflicting management objectives: namely, minimization of maintenance and repair costs, maximization of roof section performance and minimization of risk of failure (Lounis et al. 1998).

2.4.4 Value-engineering (VE)

VE principles are used as a decision-making tool. It is based on a qualitative analysis, which employs quantitative analysis within. VE principles are used to evaluate different feasible options and to choose the most optimal one among a set of economically feasible alternatives as obtained from the economic analysis.

2.5 Roofing system maintenance operations management

In arriving at this final step of five in the framework, it has been firmly established that maintenance management practice such as carrying out regular condition assessment, general maintenance, localized repair and systematic renewal, or some combinations of these practices, was found to be the best option for minimizing life cycle costs, maximizing performance, and minimizing risk. The management of the maintenance operations required to complete these activities then can take place. This includes planning, scheduling, budgeting of in-house or procured resources, identifying work methods, managing the associated document flow, etc. It is thought that assigning priorities and allocating resources in carrying out a maintenance management practice for roofs would depend on several factors. Some of these factors are probability of facility shutdown, importance of occupancy affected and consequences of failure which are translated into cost figures, including cost of disruption, cost due to relocation, and cost due to damaged contents under the faulty roof. In case of general maintenance, the planning of roof management operations may be minimal since the magnitude of the work is limited to the areas where roof distresses are found. In the case of roof renewal, the planning activities are similar to those of new roof construction.

3 System development

An information system is proposed to integrate the five steps forming the framework of maintenance management. The development methodology for the integrated information system follows the process-oriented methodology set by the International Alliance for Interoperability (IAI) in their projects to define Industry Foundation Classes (IFCs) (IAI 1998). The aim in developing IFCs is to be able to describe or conceptually model the industry project under study, which in this case, is the development of a prototype for a roofing maintenance management integrated system. The development methodology comprises of the following steps:

3.1 Usage scenarios

Usage scenarios are descriptions of situations that show the use of IFCs to carry out the selected process, i.e. developing a roofing maintenance management system. In usage scenarios, a set of assertions is made. The objective of developing assertions is to: identify classes, identify relationships, identify cardinality of relationships, and identify attributes (Liebich and Wix 1998). These assertions then can be modeled and implemented. e.g. "**A roof section can leak**". The knowledge of the roof section that leaks involves identifying the building for which a complaint about the leaky roof was made.

Example assertion:

A roof section can leak

- A **building** *contains* one or more **roof sections**
- A **roof section** *is characterized by* ***Section name, area and perimeter***

Legend: **Class**|*Relationship*|Cardinality|***Attribute***

Fig. 2: Assertion example in a usage scenario

3.2 Process definition

A process definition includes a description of the tasks involved to carry out the selected process. Fig. 3 through 7 are process diagrams that outline the tasks involved in carrying out each of the five steps (processes) in roofing maintenance management. It can be observed that the ending task in one step (process) is the beginning task in the following step (process). The figures provide the logical sequence of the tasks within each step and associated information requirements.

Step 1 - Identify roofing system components requiring assessment

Process Definition: The purpose of this process is to identify the components within the roofing system assembly that may require maintenance operations within their service life.

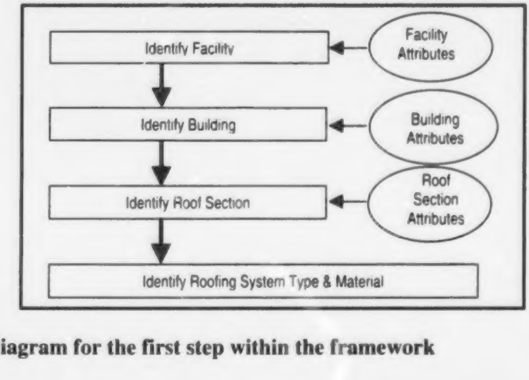

Fig. 3: Process diagram for the first step within the framework

F 1

Step 2 - Identify roofing system performance requirements

Process Definition: The tasks within this process involve identifying the performance requirements of both the roofing system as a unified entity, and the components that make-up the assembly of the roofing system.

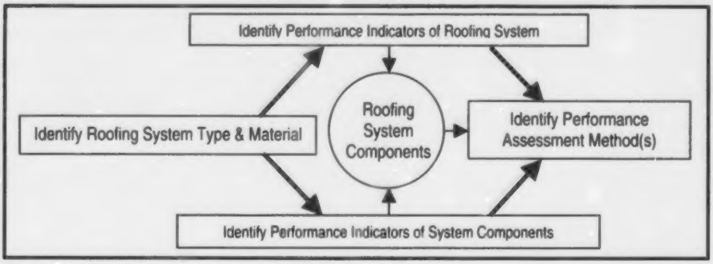
Identify Performance Indicators of Roofing System
Identify Roofing System Type & Material
Roofing System Components
Identify Performance Assessment Method(s)
Identify Performance Indicators of System Components

Fig. 4: Process diagram for the second step within the framework

Step 3 - Identify roofing system performance assessment methods

Process Definition: The purpose of this process is to identify the performance assessment method(s) to be able to catalog the system components that cease to meet the performance requirements and, hence, require maintenance actions.

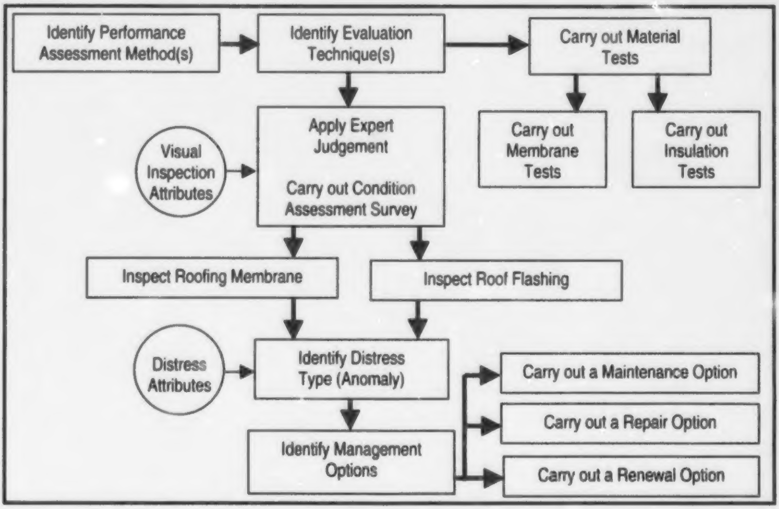
Identify Performance Assessment Method(s)
Identify Evaluation Technique(s)
Carry out Material Tests
Carry out Membrane Tests
Carry out Insulation Tests
Visual Inspection Attributes
Apply Expert Judgement
Carry out Condition Assessment Survey
Inspect Roofing Membrane
Inspect Roof Flashing
Distress Attributes
Identify Distress Type (Anomaly)
Identify Management Options
Carry out a Maintenance Option
Carry out a Repair Option
Carry out a Renewal Option

Fig. 5: Process diagram for the third step within the framework

Step 4 – Roofing system maintenance planning

Process Definition: The purpose of this process is to determine maintenance priorities based on four main analyses: performance and service life prediction analysis, life cycle costing analysis, analysis of conflicting management objectives and value engineering analysis, hence recommending the most feasible maintenance action

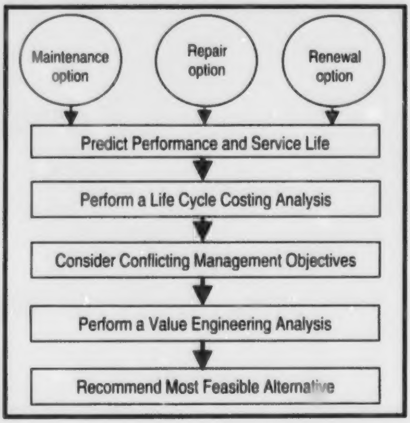
Maintenance option
Repair option
Renewal option
Predict Performance and Service Life
Perform a Life Cycle Costing Analysis
Consider Conflicting Management Objectives
Perform a Value Engineering Analysis
Recommend Most Feasible Alternative

Fig. 6: Process diagram for the fourth step within the framework

Step 5 – Roofing system maintenance operations management

Process Definition: The purpose of this process is to identify the activities involved when carrying out a roofing system renewal option. The other two options include: general maintenance (which can be carried out during the visual inspection) and localized repairs.

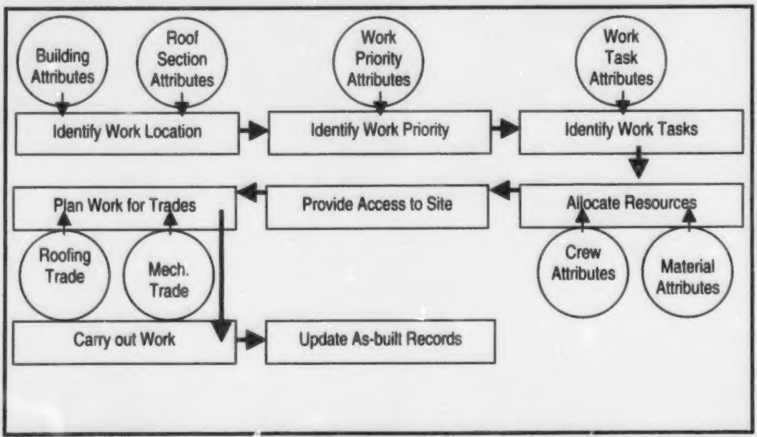

Fig. 7: Process diagram for the fifth step within the framework

3.3 Information analysis

The high level information input and output requirements of each process step (as obtained from the process definition phase) are used to define detailed data elements (e.g. classes or entities and their attributes).

3.4 Information modeling and validation

In this stage, the results from the information analysis are transferred into a conceptual model, illustrated with simplified diagrams using an informal Express-G graphical notation. Information elements are represented as classes (entities), attributes, and entity relationships.

Vanier (1998) in a paper addressing the issues of how to handle the archival and retrieval of historic information; and how to ensure the upwards compatibility of data, systems and models for the purpose of exchange of data, presented a product model for roofing maintenance. This product model is developed with the purpose of storing data on visual inspections during the life cycle of the roofing system.

Fig. 8 illustrates a portion of the product model (under development) for the proposed framework of roofing maintenance management outlined earlier. The intended product model aims at integrating the five steps (processes) which form the structure of the framework. The figure only shows the classes (entities) as gleaned from the process definition stage.

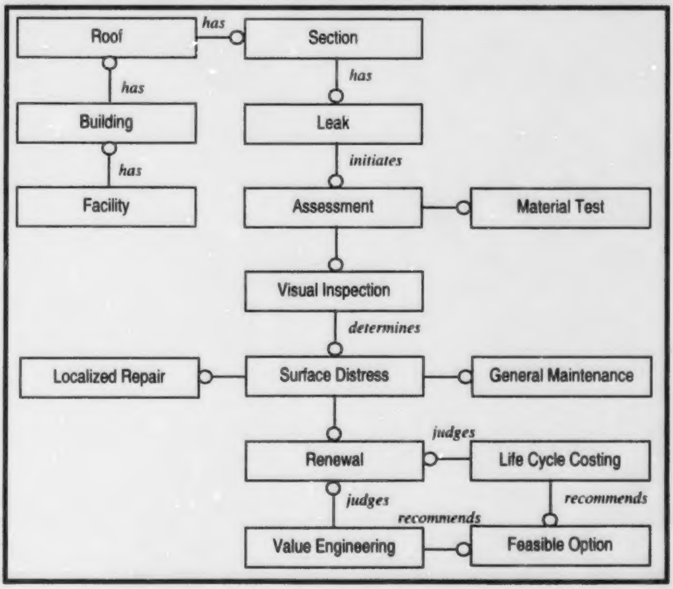

Fig. 8: Portion of the integrated framework of roofing maintenance management product model

4 Conclusions

This paper has introduced the development of a framework for integrating the steps involved in managing maintenance operations of flat or low-sloped roofing systems. The framework is built on five main steps, starting with the current condition of a roofing system in hand, and ending with updating as-built records. Currently, the development of the integrated framework is at its information modeling and validation stage. An implementation phase will follow the design stage of the prototype model. Data for the purpose of testing the prototype will be obtained in collaboration with the BELCAM project. This will serve as quantitative validation for the developed model. Results from complete prototype implementation and validation will be made available in future publications.

5 Acknowledgement

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257 A BUILDING LIFE-CYCLE INFORMATION SYSTEM FOR TRACKING BUILDING PERFORMANCE METRICS

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Abstract

Buildings often do not perform as well in practice as expected during pre-design planning, nor as intended at the design stage. While this statement is generally considered to be true, it is difficult to quantify the impacts and long-term economic implications of a building in which performance does not meet expectations. This leads to a building process that is devoid of quantitative feedback that could be used to detect and correct problems both in an individual building and in the building process itself. One key element in this situation is the lack of a standardized method for documenting and communicating information about the intended performance of a building. This paper describes the Building Life-cycle Information System (BLISS); designed to manage a wide range of building related information across the life cycle of a building project. BLISS is based on the Industry Foundation Classes (IFC) developed by the International Alliance for Interoperability. A BLISS extension to the IFC that adds classes for building performance metrics is described. Metracker, a prototype tool for tracking performance metrics across the building life cycle, is presented.

Keywords: life-cycle information management, performance metrics, performance assurance, information technology, industry foundation classes, software interoperability, commissioning, design intent

1 Introduction

Buildings often do not perform as well in practice as expected during pre-design planning, nor as intended at the design stage, nor even as measured during commissioning and maintenance operations. While this statement is generally

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considered to be true, it is difficult to quantify the impacts and long-term economic implications of a building in which performance does not meet expectations. This leads to a building process that is devoid of quantitative feedback that could be used to detect and correct problems both in an individual building and in the building process itself.

A key element in this situation is the lack of a standardized method for documenting and communicating information about the intended and actual performance of a building. This deficiency leads to several shortcomings in the life-cycle management of building information. Planners have no means of clearly specifying their expectations. Designers cannot concisely document their design intent. Commissioning personnel have no standardized method for documenting the results of performance testing. Post-occupancy building performance cannot readily be compared to expectations in an attempt to evaluate and improve design and operation decisions. Lastly, without quantification of the magnitude of performance problems it is difficult to motivate building process participants to alter their current practice.

This paper describes the Building Life-cycle Information System (BLISS); designed to manage a wide range of building related information across the life cycle of a building project. An initial implementation of BLISS is based on the International Alliance for Interoperability's (IAI) Industry Foundation Classes (IFC), an evolving data model under development by a variety of architectural, engineering, and construction (AEC) industry firms and organizations (IAI 1998). A BLISS extension to the IFC that adds classes for building performance metrics is described. Metracker, a prototype tool for tracking performance metrics across the building life cycle, developed to address the shortcomings identified above, is presented.

2 A building life-cycle information system (BLISS)

The overall concept behind a building life-cycle information system is to provide a distributed computing environment for managing, archiving, and providing access to the wide variety of data that are generated across the complete life cycle of a building project. One goal of providing such a system is to initiate the industry-wide development and standardization of an interoperable set of tools to address a variety of information transfer problems in the building life cycle. Each individual tool must be tailored to respond to the needs of project participants within a specific phase of the project life cycle. Yet the data used and produced by each of these tools must also be standardized to allow interconnection through a common information infrastructure.

Figure 1 shows a high-level representation of the key elements of our Building Life-cycle Information System (BLISS). One element of such an information system is a detailed data model describing the physical components and systems contained within a building design, such as walls, windows, spaces, and HVAC and lighting equipment. This type of data model is commonly referred to as a product model. We believe that in addition to a product model, the system must also contain a clear and concise representation of the performance objectives for a building project, discussed in more detail in the following section. Furthermore, by capturing the relationship between performance objectives and the product components selected to achieve these objectives, we have a means of documenting the rationale behind design decisions. Within BLISS, this combination of informational elements is maintained for various building versions as the project moves through its life cycle. This provides an historical record of previous versions along with the current version.

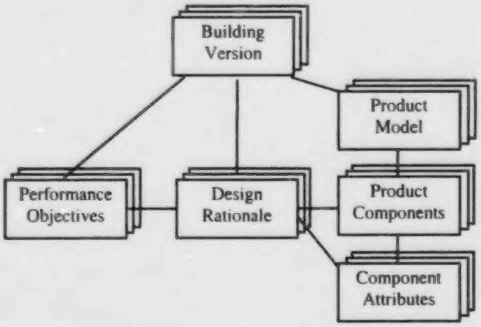


Fig. 1: Key elements of a building life-cycle information system

2.1 Performance objectives and metrics

A building project begins with a consideration of the various performance objectives of interest to building stakeholders. While primary attention is generally given to space requirements and construction costs, a wide spectrum of objectives may be at least informally considered at this stage, including: life-cycle economics; energy-efficiency; environmental impact; occupant health, comfort and productivity; and building functionality, adaptability, durability, and sustainability. The process of identifying the objectives for a given building project is often referred to as programming. The outcome of programming is most commonly recorded in text that becomes part of design and construction documentation. This documentation may be frequently referenced during design, and occasionally referenced during construction, but then most often collects dust from that time forward.

Performance metrics are designed to explicitly represent project objectives, using quantitative criteria, in a dynamic, structured format that provides value across the life cycle of a building project. One or more metrics may be defined for any given performance objective that building process participants (e.g., owners, designers, operators, occupants) wish to specify and track. A guiding principle in defining a performance metric is to identify a critical variable that measures, reflects, or significantly influences a particular performance objective. To be useful across the building project life cycle, each metric must also be capable of being either predicted or measured at various stages of the project so that the achievement of each objective can be evaluated.

In most instances, a high-level performance objective will need to be delineated by multiple metrics that influence its overall satisfaction. This delineation can be organized hierarchically. The hierarchy in Figure 2 shows one possible subset of performance metrics that could be used to specify, track, and maintain energy-efficiency in a building. Note that each performance metric is not necessarily a simple arithmetic sum of its constituent metrics. The hierarchical organization logically groups metrics that are important to track because of their impact on their parent metric. For example, one component of whole-building energy performance is the cooling system energy use intensity (Cooling EUI) which in turn is influenced by chiller and cooling tower efficiencies and building cooling load, among other possible elements.

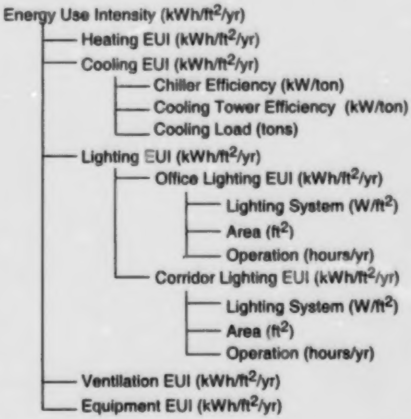

Energy Use Intensity (kWh/ft²/yr)
Heating EUI (kWh/ft²/yr)
Cooling EUI (kWh/ft²/yr)
Chiller Efficiency (kW/ton)
Cooling Tower Efficiency (kW/ton)
Cooling Load (tons)
Lighting EUI (kWh/ft²/yr)
Office Lighting EUI (kWh/ft²/yr)
Lighting System (W/ft²)
Area (ft²)
Operation (hours/yr)
Corridor Lighting EUI (kWh/ft²/yr)
Lighting System (W/ft²)
Area (ft²)
Operation (hours/yr)
Ventilation EUI (kWh/ft²/yr)
Equipment EUI (kWh/ft²/yr)

Fig. 2: Performance metric breakdown for energy use intensity

Performance metrics come in a variety of forms for which there is presently little standardization. For example, chiller efficiency can be specified in numerous ways including: a single value parameter (e.g., coefficient of performance (COP) or integrated part load value (IPLV)), multiple data points representing a two-dimensional part load curve for specific operating conditions or a three-dimensional part load surface across the full operating regime, or a mathematical curve or surface function representing these same data. Moreover, the preferred method for documenting a performance metric may change over the life cycle of a project. Following the chiller efficiency example, pre-design planning might specify a desired chiller IPLV. Detailed design simulation might employ a mathematical representation (e.g., a curve fit) of the performance of the selected chiller, based on manufacturer specifications. Commissioning and operations and maintenance (O&M) measurements might subsequently collect multiple time series data points during the chiller's actual operation. The specification of a performance metric must therefore be flexible enough to accommodate this variety of forms.

Our data definition for a performance metric includes the following parameters: name, specifier, date of specification, description, benchmark value and source, and assessment value(s) and source. The metric *name* is a text identifier which we intend in the future to supplement with a standardized code for predefined sets of performance metrics. These sets will be drawn from work in this area by the industry associations such as the Green Building Challenge (GBC), the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE), and the Illuminating Engineering Society (IES) (Larsson 1993; ASHRAE/IES 1989). We also intend to solicit input from a variety of industry participants in generating these predefined metrics. The *specifier* and *date of specification* document the building process participant concerned with each building performance objective. The *benchmark value* documents the intended level of performance. The *benchmark source* archives the origin of the benchmark value (e.g., code, standard, simulation, manufacturer data). One or more *assessment values* record the performance of a building design, or an operating building, over time. The *assessment source* indicates the means by which a performance level has been assessed (e.g., simulation, measurement, estimation).

Sets of both benchmark and assessment values are archived for each performance metric over the life cycle of a building project. There may be an initial benchmark value established in pre-design planning, updated benchmark values and predicted assessment values determined during design, short-term measurements from commissioning, and long-term monitored values.

2.2 A scenario for BLISS

One of the challenges in the development and use of tools to archive performance metrics is that the metrics cannot stand on their own. They are linked, as discussed above, to design details and operating conditions that generate the specified, predicted or measured performance that is to be evaluated against a benchmark. Thus, the concept in BLISS is to ensure that there is a product model of the building that can be used to predict design performance through the use of simulation tools.

Figure 3 outlines a possible scenario for the use of performance metrics and a building life-cycle information system. The scenario begins in the programming phase (Step 1), where a set of performance metrics are selected and recorded in BLISS to represent building performance objectives. In Step 2, computer aided design tools are used for the architectural and engineering design of the building, and the resulting data are used as input to various simulation tools to predict the performance of the current design for evaluation against the desired performance. Results from the final design simulations are summarized in an updated set of performance metrics, which establish a set of benchmarks for use in commissioning. Modifications to the building design due to construction changes, or to the building operation due to occupancy or use changes, must be consistently documented in the product model to provide as-built information. Note that the impacts of these changes can be evaluated more easily and comprehensively given the data contained in BLISS. As installation of each building system is completed, commissioning tests are conducted to determine if the design intent was met (Step 3). Also at this stage, in-situ test results are used to re-calibrate simulation models and update the appropriate performance metrics. In this manner consistent up-to-date documentation of both the building and its expected performance is maintained for use during building occupancy.

In Step 4 the building automation system (BAS) is used to continuously monitor the building and provide diagnostics with real-time simulation that checks actual operation against current performance benchmarks. These data are also used in Step 5 to track O&M actions. One benefit of such integrated information systems is that one can readily identify the energy impact of O&M actions. For example, when the chillers are cleaned, the efficiency is improved and the new energy performance readily measured. O&M can therefore be optimized. The system is also linked to a retrofit simulation tool that allows the facility manager to explore the energy savings from possible major or minor system changes (Step 6). Each step involves the generation of metrics, which are archived and accessed in the common database format. The facility manager has a clear record of the design, as-built, and as-operated equipment, along with the performance of the building. Furthermore, the history of building design decisions and the resulting performance can be used to undertake post-occupancy evaluation of the building in order to better inform future designs.

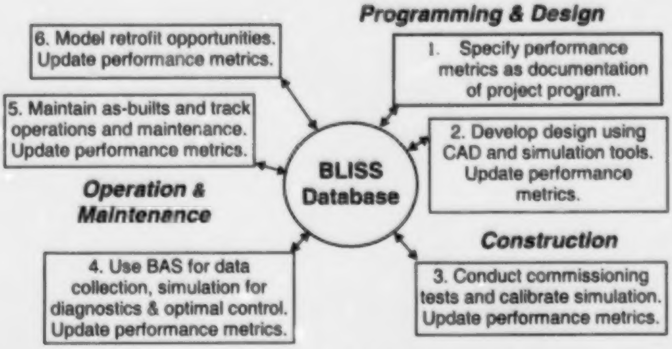

Programming & Design
6. Model retrofit opportunities. Update performance metrics.
1. Specify performance metrics as documentation of project program.
5. Maintain as-builts and track operations and maintenance. Update performance metrics.
2. Develop design using CAD and simulation tools. Update performance metrics.
BLISS Database
Operation & Maintenance
Construction
4. Use BAS for data collection, simulation for diagnostics & optimal control. Update performance metrics.
3. Conduct commissioning tests and calibrate simulation. Update performance metrics.

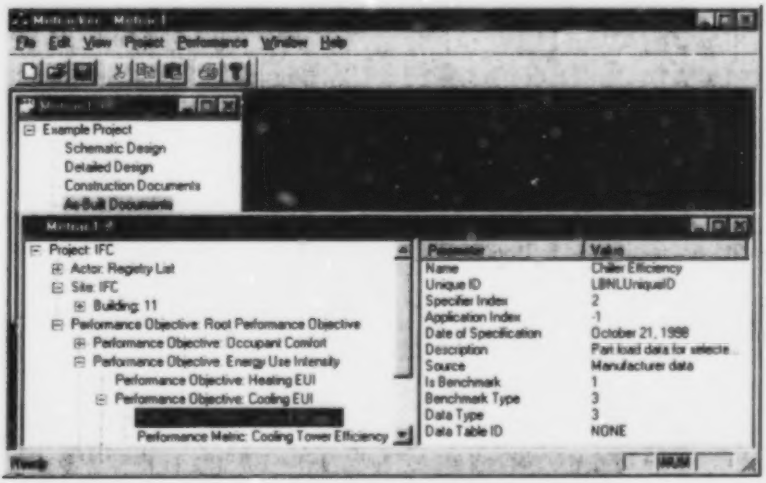
Fig. 3: Use of performance metrics through the building life cycle

3 A prototype tool for tracking performance metrics (Metracker)

We are developing a prototype implementation of a performance metric tracking tool, called Metracker, using the BLISS concepts described above. Metracker consists of a standardized data model and data exchange mechanism, and a user interface.

The Metracker prototype is built upon the IAI Industry Foundation Classes Release 1.5.1 (IFC1.5.1) data model extended with our definition of building performance metrics. The performance metric extensions to the IFC1.5.1 data model conform to IAI prescribed methods, enabling IFC-compliant tools to exchange data with the prototype. The data exchange mechanism uses the IFC method of writing and reading STEP Express files, an international standard for the exchange of product data. We are working to incorporate the performance metric data classes in future releases of the IFC. In the meantime, only those tools that are cognizant of the performance metric extensions will be able to interpret these data. However, any IFC-compliant tool will be able to read and pass on the data intact to other tools.

The user interface for Metracker focuses attention on the specification, tracking, and visualization of performance metrics. This is accomplished through a data browser that displays the organization and details of a BLISS archive, and graphical visualization of performance metric data comparing intended and actual performance across the building life cycle. Figure 4 shows an example of the Metracker data browser interface.



- Example Project
  - Schematic Design
  - Detailed Design
  - Construction Documents
  - As-Built Documents

- Project: IFC
  - Actor: Registry List
  - Site: IFC
    - Building: 11
  - Performance Objective: Root Performance Objective
    - Performance Objective: Occupant Comfort
    - Performance Objective: Energy Use Intensity
      - Performance Objective: Heating EUI
      - Performance Objective: Cooling EUI
        - Performance Metric: Cooling Tower Efficiency

Parameter	Value
Name	Chiller Efficiency
Unique ID	LBNLUniqueID
Specifier Index	2
Application Index	-1
Date of Specification	October 21, 1998
Description	Part load data for selecte...
Source	Manufacturer data
Is Benchmark	1
Benchmark Type	3
Data Type	3
Data Table ID	NONE

Fig. 4: Metracker data browser

The smaller window in the upper left lists multiple building versions that have been archived in a hypothetical BLISS project named Example Project. The left pane of the lower window displays a hierarchical tree of the various objects (e.g., Actor, Site, Building, Performance Objective, and Performance Metric) that have been instantiated as part of the selected building version (As-Built Documents as shown here). The right pane of the lower window displays the parameters of the selected object and their values.

In this figure, the parameters for the performance metric Chiller Efficiency are shown. In this instance, this is a metric benchmark that will contain manufacturer data for the part load efficiency of a chiller. The zero-based index values for several enumerated types are shown here instead of more descriptive values. These include Specifier and Application indexes which denote the actor and application that created this particular performance metric. The details of each actor and application are contained in separate lists within the archive. Also, Benchmark and Data Type indexes identify the type of benchmark and the type of data defined for this metric. We are still in the process of determining the most appropriate types for these metric parameters. As of this writing, benchmark types include minimum, maximum, range, target with tolerance, and distribution. Data types presently include scalar, vector, two-dimensional matrix, three-dimensional matrix, frequency distribution, and time series.

Metracker is still under development and in-house testing. We are now working on the data visualization portion that will graphically display the metric data. We plan to field test the prototype this year and enhance both the tool and the underlying data model through the lessons learned. As previously stated, we are also working within the framework of the IAI to incorporate performance metric data classes in future releases of the IFC.

By making this type of data broadly available to a variety of building industry software tools and end-users, we hope to continue toward our goal of a new generation of buildings that perform as intended by design.

4 Acknowledgments

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Hitchcock, R.J., Selkowitz, S., Piette, M.A., Papamichael, K., and Olken, F. (1997) Building performance assurance through improved life-cycle information management and interoperable computer tools. *Proceedings of the Fifth National Conference on Building Commissioning*, April 28-30, Long Beach, CA.

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258 REVERSE PROPAGATION OF DATA FOR BUILDING MANAGEMENT

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Abstract

Lifetime data for the management of buildings is becoming more feasible and is now expected by more facilities managers. It should be possible to extract the data related to the building fabric and systems from that generated during design and construction. For this to be just what the users require and in the form they require it, depends upon their involvement at an early stage of a project. Reverse propagation can then enable their wishes to influence the data collected so that redundant data is not produced and does not cause confusion. New forms of procurement such as partnering, allow this early involvement; alternatively there must be standards to define the general form of management data. In Denmark the CIS-CAD system defines a simple format being tested on a series of projects. It extracts information needed for statutory authorities and management, and examples are given based on continuing experience of its use. The principles of reverse propagation are discussed and the trend in databases to allow input from both ends of the process. This will eventually allow a more precise and economic definition of the building model and core data needed for management.

Keywords: building management, facilities, model, CAD, reverse propagation

1 Introduction

Like any new discipline, Facilities Management has grown beyond its original requirements for managing buildings more effectively. As the value of property has risen, and the demands of occupants have increased, the need for better management of the space occupied by a business has resulted in a major industry. The field of FM

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now requires a wide range of management techniques (Alexander 1997) including:

- Quality management
- Value management
- Risk management
- Environmental management
- Information management
- Project management

This diversity has tended to make FM just another management discipline and to relegate the building fabric to a minor element within the total operation of a business. There is a need for those in construction to focus on building management which regards a building as an organism which is defined at conception and should carry useful data with it throughout its life.

It is perhaps understandable that property owners, acquiring several buildings of different ages, will want to resurvey each of them to capture data needed for management in the form that suits their policy. However, a growing number of new buildings are constructed from data models that contain much of the data needed for management. Until now it has been difficult for the eventual user of a building to specify the content and format of the data needed. But, with new forms of procurement, such as partnering and Design, Build and Operate, the user and owner are more likely to be known when design commences.

Any building project involves a growing body of information, from the client's brief, added to by designers, given as instructions to contractors and, sometimes, data specifically added for maintenance and control of the resulting building. This has led to a one-directional structure adding detail as the process develops and often resulting in an excess of information which may be passed on to building managers in an unsuitable form. The reason for generating excess information is that so often disputes in building result from inadequate, or late, information. With the new spirit of partnering promoted in the UK by the Latham (Latham 1994) and Egan (Egan 1998) reports, a more efficient and effective exchange of data should be possible.

2 New patterns of project data

Information technology, particularly that of databases, has developed from a hierarchical form (1), to a network of relational items, and now to classes of objects sharing and inheriting attributes. The implication is still that data is input from the beginning of a process and extracted at the later stages (2). A more useful approach, involving reverse propagation, would be to think of the necessary data being specified from either end of a process, and being supplied by the most appropriate member of the project team (3). Each member of the team can then extract only the data they need from the building model which they have helped to specify. Fig 1.

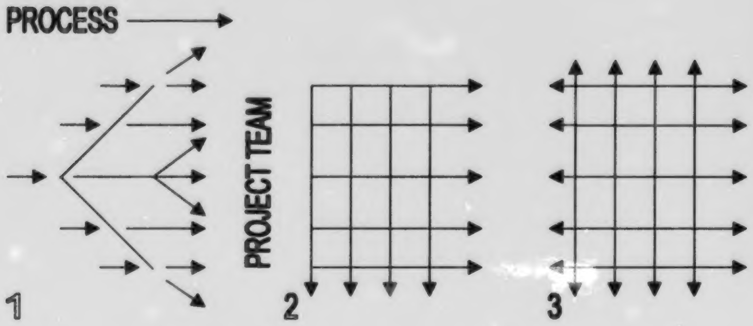

Fig. 1: Development of project data flows towards a reverse propagation network

With reverse propagation, the data needed is specified by the user, and the total data set should not exceed that specified by all those involved in a project at some stage. The client inputs the basic requirement but is advised by the designers what is possible and what additional data is needed. The designers' instructions can meet the specified needs of a pre-appointed contractor, who can add experience from a production model such as that proposed in Model Based Construction Process Management (Laitinen 1998). Product manufacturers and specialist suppliers now contribute more data to a building project and the managers of the building, if involved early, can specify the data they need for operation and maintenance. The result should be the elimination of data that is transferred because one member of the team is ignorant of the needs of others or fearful of not providing enough.

Reverse propagation is carried out in several stages with the data user's requirements being specified first, input of this data by designers and contractors, then delivery of just the data needed when the project is completed. An example might be performance specification where a designer describes the conditions which a product or material has to fulfil, and suppliers will offer their solutions to be selected by the designer or contractor. The customer is given increasing importance in new ways of organising the building process. This should involve the building manager in specifying the needs for management data. The project team then have to respond to this by ensuring that it is included within all the project data and that it can be extracted and delivered on completion of the building. Reverse propagation just reflects the customer's importance in the organisation of building data.

3 Types of data used on a building project

If the types of data on a building project are analysed, they can be classified as:

- General data on building
- Required by statutory authorities
- Specified by the client
- Required for development and analysis of the design
- Required for presenting the design to client, authorities, public, etc
- Instructions to contractors and suppliers
- Instructions for maintaining and managing a building

To these can be added the administrative data needed to establish the relationships and responsibilities of those involved, and the inevitable missing items that no one has specified and which can cause problems at the later stages of a project.

Types of data that are superfluous after completion of construction include: much of the general data on building, some of that required by statutory authorities, design analysis apart from that which might be required in altering the building, presentation material used to inform or impress the client, and instructions to contractors which do not contain information on the materials or components used in the building. Often this data is passed over to building managers when their real needs lie in instructions for maintenance and control of systems in the building.

With traditional contracts there is a general understanding of the data needed by each member of the team and who usually supplies it. In newer forms of procurement these questions, on the data needed and responsibility for its supply, must be redefined. The British Property Federation proposed a form of contract in the UK in the 1980s which defined the roles of design manager and construction manager, and the deliverables which each designer and contractor should provide. It proposed relating payment to receipt of these, whether they were drawings delivered by designers or work packages completed by contractors. But for a few trial projects, this form of contract has been little used in spite of its clear definition of responsibilities.

4 The Danish CIS-CAD documentation

An example of reverse propagation is a Danish building ministry sponsored project started in 1994 to define the data needed by various users to manage and administer completed buildings. It was carried out by the BPS centret with representatives of the ministry and advised by a project group of experienced architects, engineers and contractors. It was revised under a project led by Ejvind Alf Jensen and published as a set of guidelines in 1997 (Boligministeriet 97). It has been tried on several housing projects, some of which have now been completed, and the experience of the data management published. CIS-CAD regards the building model, used in the design and construction process, as a resource for feeding three different types of database used during the building's lifetime (Fig 2).

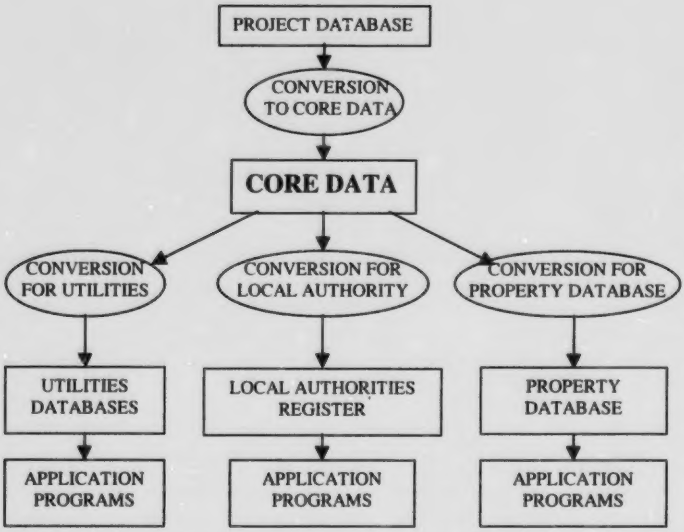

Fig. 2: Extraction of data used over the lifetime of a building - CIS-CAD

The management core data, extracted from whatever form the design and construction data takes, is defined by the needs of three main types of user:

- Utilities - connections to gas, water, electricity, drainage, and site plans.
- Public authorities for property taxes, floor areas, standards addresses, etc
- Building owners and managers for management and maintenance

Some of this data is not very demanding but needs to be in conventional form. The location of connections to the main services, and the calculation of floor areas, must be given in precisely the form specified by the relevant authorities. Building management data is more substantial but, where a building is commissioned by the organisation which will manage it, and this is relatively common in Denmark, the requirements for floor plans, details of equipment, maintenance schedules, etc, can be specified for extraction from the design data.

CIS-CAD is realistic about models being defined in drawings, specifications and quantities documents for some time yet, but requires the elements of building to be regarded as objects. These are not necessarily objects in object-oriented systems or Industry Foundation Class terms, but commonly coded elements which can be linked by their codes. These codes are based on SfB Table 1 elements but add details required by the authorities using the data. The system has yet to be widely deployed but a number of trial projects have been carried out and it is strongly promoted by the building ministry.

Experience has shown that building owners typically require data at one of two levels: just the site plan with administrative data, or a more complex model of the building. At present few buildings in Denmark are designed using objects, although the IT barometer survey showed a move towards more sophisticated CAD data structures (Howard 1998). The Point add-on to Autocad is widely used and it can provide object-based building models for CIS-CAD although these are not yet based on the Industry Foundation Classes.

5 An example of CIS-CAD on a project

In 1996 a housing project in Naestved was built to a data structure based on CIS-CAD used by the architects and engineers, but the Kommune which managed the buildings did not then have sufficient CAD facilities to take over the graphic data. A more complete example, which is still being built, is at Aalborg University where Poul Sorgenfri Ottosen of the technical administration is leading some research into management of buildings with advanced data structures. This is the second stage of sector 8 and is again being designed by the consultants, Dall & Lindhartsen architects and Carl Bro, engineers, using objects organised by SfB Table 1. (Fig 3)

Fig. 3: Image from Project Web site of new humanities building at Aalborg University

The core data from these objects will be taken over by the technical administration and used to manage the building based on CIS-CAD. However CIS-CAD will need to change its current structure to be fully compliant with the SfB codes which have been used by the designers. A detailed description of this important project is given in two reports from Aalborg University (Aalborg 96 and 98). Poul Sorgenfri Ottosen will be describing the design process and its relation to the Industry Foundation Classes in another paper. The Building Ministry is supporting the work on CIS-CAD and helping to ensure that the experience of using it is widely known. This project is also of interest because the documents are held on a Web site accessible to the firms involved, using a system called Project Web developed by Carl Bro A/S. Once the data is held in a form which continues throughout the duration of a project and all those, including clients and managers have access to it from the beginning, then reverse propagation of the needs of users becomes possible.

6 Use of FM systems in Denmark

One potential problem with making management data available to client organisations is that they may be using different facilities management systems to handle the data. If the data structures and formats of their systems are known at the beginning of the project, it may be possible to provide data in the right form, but it would be preferable to have a common interchange format for FM systems, better than the 2D DXF or DWG formats from Autocad. A study of the use of facilities management software systems carried out by CIS-CAD (Boligministeriet 98) shows this diversity. Although the use of such systems is at an early stage, the market is shared by a number of different systems. These will each have their own data structure although four use Autocad for their graphic data and two others use the SQL database standard.

SYSTEM NAME	ARCHIBUS	AUTO FM	POINT FM	CARETAKER	DRIFTCHEFEN	F M A	FRONTINUS	TIPS
DANISH OWNER/ DISTRIBUTER	Dana Data	Berendsen Components	CAD Point	COWI	KeyCon	Scan CAD/ Aalborg Univ.	Bascon	NNR
ALL USERS	>50000	Ca 500	100	Ca 400	102	20	50	100
DENMARK	Ca 20	15	10	Ca 300	52	20	50	1
MAIN MODULES	Space Autocad Furniture Telecom Operatns Lease	Areas Location Personel Telecom Register Barcodes	Areas Coredata Property and Building	Coredata Maintenance Budgets Contracts	Services Energy Photos	Areas Maintenance Purchase Budget	Standard system with modules	Areas Energy Fire Services Maintenance
DATA STRUCTURE	Object oriented	Object oriented	Current standards	Hierarchical	Object oriented	Object oriented	Hierarchical	Relational database
LINKED SYSTEMS	Many Eg SAP	Special interface	Via SQL	Sybase SQL	Yes	Excel	Windows programs	
LINKED GRAPHICS	Autocad	Autocad Intellicad	Autocad	Document manager	Can read all formats	Autocad	Links to drawing	IBM AE Series

Fig. 4: Table with some properties of FM systems available in Denmark

7 The trend towards reverse propagation

Reverse propagation of data requires all those contributing to, or using, it to be involved from an early stage. All links into the data model should be two way with early input of their requirements by users of the data. Where some partners are unknown, conventions or standards, where they exist, must be relied upon. Model sets of data for building management would be a great advantage since so few building occupants are known from the beginning of a project and they may change throughout the life of the building. Most countries already have standard definitions of construction data, for example the Coordinated Project Information system in the UK (CPI 1987), but these are based upon traditional forms of document and elements within them, such as the Standard Method of Measurement for building quantities in CPI, are more detailed than the user of the data requires.

With partnering arrangements in place, an early task in any project should be for the team to discuss data requirements and formats. The standards on CAD layers, both international (ISO 13567, 1997) and British (BS 1192 Part5, 1998), define how to structure CAD data, but the British standard also gives management guidelines on the items that need to be agreed with regard to roles and responsibilities. This is the opportunity to ensure that the data transferred between the partners is not excessive. In Denmark, the PPB housing consortia carrying out a series of experimental, typically prefabricated, housing projects, refer to their relationships as 'vertical integration' which is similar to partnering. When the benefits of this have been assessed by various research projects at DTU, it may demonstrate the benefits of continuous relationships on a series of projects.

It is only these long term links which allow the end users of data to be involved from the beginning and to specify the type and form of data they require. More such projects will allow the benefits of reverse propagation to be clearly established and for redundant information to be kept to the minimum. There is valuable experience being gained in Denmark of the use of relatively simple systems for transferring data from building design to management. This does require the needs of building managers to be known and, when their general or specific requirements are defined at an early stage, the benefits of reverse propagation can be attained.

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259 THE BENEFITS AND COSTS OF INFORMATION TECHNOLOGY SYSTEMS IN BUILDING MAINTENANCE MANAGEMENT BASED ON INTERVIEWS

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Abstract

This is an introduction to how the benefits and costs of information technology (IT) systems of building maintenance management are evaluated in thirteen Finnish real estate companies. The focus is on maintenance systems, however the links to the other parts of real estate management are not forgotten. The benefits of the new IT-system are divided into performance, savings and bigger incomes. The evaluation of IT-systems includes assessing the usability, functions, integration to other systems, presentation quality, life cycle of software, references, ergonomy and price. The costs and benefits are forecast for several years to check the profitability of the investment.

Keywords: Information technology, cost-benefit evaluation, building maintenance management

1 Introduction

This paper is part of a research project financed by VERA (Information Networking in the Construction Process, a technology programme of Tekes, Technology Development Centre) and seven companies. The project is focused on the strategic development of information technology systems for real estate management. In this paper the IT development in rather small real estate companies is studied by classifying the typical steps in making cost-benefit evaluation. The knowledge is based on interviews with employees of thirteen companies (appendix A) and checked the answers later. The author used theme interview approach in 1998 (appendix B). The aim was to clarify the state of the art of IT-systems. The focus of this paper is on maintenance management.

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2 Maintenance management

Maintenance refers to keeping, holding, sustaining or preserving a building and its services at an acceptable standard to enable it to fulfil its function. This can take the form of a planned maintenance programme or emergency corrective maintenance. One of the most important things is to optimise the planning of maintenance activities.

Preventive actions in maintenance can reduce costs by 14-15 % in blocks of flats, if damage can be avoided (Kuusela, 1998). On the other hand, preventive maintenance may cost twice as much as reactive maintenance if the lifecycle of the product is assumed to be short. The optimisation of maintenance action is important.

Maintenance manuals have been required for two years for residential buildings that are financed by the Finnish government (Pirinen et al. 1996). Last year also the prototype of maintenance manual for office buildings was created by RAKLI (The Finnish Association of Building Owners and Construction Clients). The maintenance manual gives guidelines for maintenance management. The manuals mentioned are in test use. The manuals are sometimes criticised for being forgotten paper documents. IT technology gives possibility of handling this information in a more rational way.

As far as is known, real estate managers in Finland use IT at a level of 100 % in bookkeeping operations. IT-systems of maintenance management are used in about half of the companies. The software companies that sell these applications have started this business in the 1980s or later. According to Kiviniemi (1997) half of the total of real estate companies planned to develop IT-systems for maintenance management in a one to three years time span. About one third of the companies already used IT in this field, and they claimed that the applications were rather mature. In the near future the companies planned to develop databases of suppliers and project management tools.

There could be found four different types of IT systems for maintenance management in the interviewed companies:

- Maintenance manuals for residential buildings - based on government instructions
- A maintenance system which is integrated with bookkeeping and facilities management
- Advanced heating, air ventilation, lightning and other environment maintenance systems - with automatic control systems, bookkeeping and performance control
- Spreadsheet based own systems by which the energy consumption is monitored or/and repair databases are managed.

3 Benefits

The objectives of the IT-investment varies according to the state of the business (figure 1). When a company has cash flow problems it will focus on lowest cost, purpose-made-systems. When the company is growing fast the preferred solution is to bolt-on new products to "bolster" the existing system. The company tries to sort out the capacity problem and the company especially worries about customer care. After bolting on systems the company finds out that it is not economically viable to continue this process. The decision is taken to commission a total solution replacement. All the old information has to replaced. Often this replacement is even more expensive than the replacement system itself. Taking full advantage of fully functional systems, the processes of the company must be re-engineered around the new system.

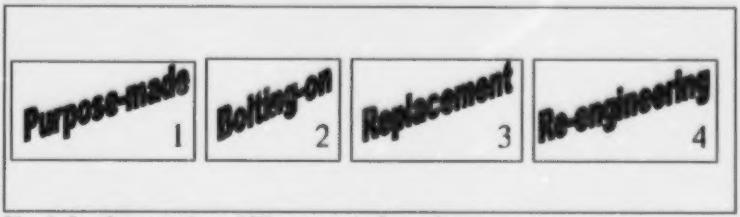

Fig. 1: Implementation of IT systems in four phases

The implementation of IT systems has followed that path in the companies interviewed (thirteen Finnish real estate companies). Now half of the companies are facing the stage where the bolt-on systems are no longer viable and they are searching for total solution replacements.

Benefits of the new IT-system are divided into performance, savings and bigger incomes. The companies pursue better service, faster processes, so called performance benefits. Economic factors are checked to avoid the unprofitable solutions. Estimation of benefits is often based on the software producers presentations. Deep-going verification like testing several solutions can be done only in large companies. The companies quite often co-operate and ask each other's opinions on the software they find attractive.

Evaluation of IT systems includes assessing the usability, functions, integration to other systems, presentation quality, life cycle of software, references, ergonomy and price. One result from the interviews is that when evaluating the IT-systems, companies use three types of information:

1) Experiences from internal processes - restrictions, visions and problems
2) Collection and elaboration of external information
3) Exchange and communication of information between software companies and own organisation. (Naaranoja and Östman 1998)

4 Costs

Cost evaluation of IT-systems did not vary in the interviewed companies. The bigger the investment the more time was used to evaluate the costs. Normally the costs and benefits are forecast for several years to check the profitability of the IT investment. Costs can be divided into development costs and ongoing efforts – like saving backups, updating the software and error handling. The time needed to implement the project is very difficult to estimate. If accurate expenses are needed the experts themselves forecast how much time they need to work. The rest of the time is spent with administration and other work.

It is easy to ask the prices of new hardware and software, but estimating the functions of different solutions is difficult. Usability is one of the most important things in evaluating the training time and use of old information. All the other costs, including testing, need to be remembered. The time for testing is often underestimated.

The maintenance has to be defined for example who will update the data in the system since if the data is not reliable the solution cannot be used efficiently. The number of hours used in IT service varies a lot in different organizations. Especially small companies use software companies to support their IT-systems and they buy the service from there.

5 Conclusion

This study has shown that the evaluation of benefits of IT-systems is based on the experiences of internal processes like the phase of implementation of the IT system: purpose-made; bolting-on; replacement; or re-engineering. This influences what kind of benefits the company is pursuing and also how much money the company may use in evaluations of different software solutions. It would be interesting to study how benefits could be forecasted and how the performance should be changed when aligned with the new IT-system. The relationship between partners and real estate companies is also interesting. Can a real estate company force the partner to use more intelligent systems than they would voluntarily use, can companies jump from the purpose-made IT-systems stage to re-engineering?

Companies find cost/benefit evaluation difficult. They have to rely on software companies and their reference lists and experiences of other companies when purchasing new IT-systems. In Finland the software companies that work in this area are relatively small and they customise their products quite much, so the wishes of the real estate companies are well known. However, product development in real estate companies is needed since the IT-systems enable such functions that have not been possible before and the re-engineering would give the most powerful benefits.

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Appendix A: Real estate companies and people that have been interviewed:

- Halli Ltd, Heikki Punkari, Markku Törmä
- Pikipruukki kiinteistöt Ltd, Birgit Mäkinen
- Wärtsilä Nsd, Asko Hartman
- Svenska Österbottens Förbund, Ossian Westlin
- Vaasa town, Markku Ahola
- Valtion kiinteistölaitos, Pentti Aromaa
- Reikälevy Ltd, Matti Mäki-Haapoja
- Ruukin kiinteistöt Ltd, Kalervo Saarimaa
- VOAS Ltd, Eila Kultti
- Soleado Ltd, Juho Sillanpää
- ABB-kiinteistöpalvelut Ltd, Jouni Väkeväinen, Matti Malmberg
- Kokkola town, Göran Björkgård
- Hermia Ltd, Olli Niemi

Appendix B: English version of theme interview questions

1. How have you developed your IT-systems? Where did the development idea come from?
2. How have you evaluated costs/benefits of your IT-investment?
3. What kind of time span do you use for the evaluation of your IT investments?
4. How did you create your IT strategy if you have any?

260 LIFE-CYCLE COST DESIGN METHODS AND TOOLS

S. Pulakka

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Abstract

Life cycle economics is the only way to control individual buildings and real estate over long terms. VTT, in co-operation with two consulting firms has developed a systematic way to apply life-cycle economics on different stages of building design. This model has been presented in this paper. It is based on investment costs modified to annual costs, yearly maintenance costs, renovation costs modified to annual costs as well as on an analysis of benefits like incomes, effects on quality, and other nonqualified factors.

Keywords: life cycle economics, building design

1 Introduction

This Life-Cycle Cost Estimation Methods (LCC) project has been carried out in co-operation with two Finnish consulting companies, Granlund Olof Oy and Rapal Oy, and VTT Building Technology research organisation. The project was partly financed by the Technology Development Centre of Finland (TEKES) and ended in Dec., 1997.

2 Need for LCC methods and tools

The interviews with Finnish facility management staff and building designers have proven that there is lack of systematic methods and tools for design of buildings' life-cycle cost. However, occupancy cost are usually the second largest cost in the

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business after labour cost. So better design of life-cycle cost seems to offer quite large saving potentials. The objective of this project is to develop life-cycle cost design methods and tools which are applicable both for building maintenance and design of new or renovation objects.

Life-cycle cost analyses concern the cash flows, partly speculated, during the life-cycle of a whole building or part of it. Then planning and building costs are transformed into annual cost and also maintenance cost and periodically occurring renovation cost are taken into consideration. On the whole, life-cycle management is an iterative process aiming at the selection of the most suitable and economic solution from many alternatives. Also consideration of buildings' environmental impacts should be part of the LCC design process.

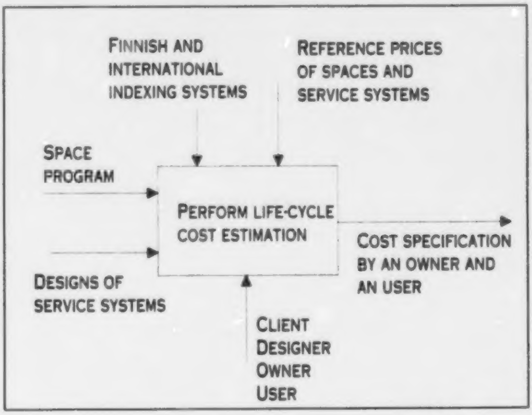
FINNISH AND INTERNATIONAL INDEXING SYSTEMS
REFERENCE PRICES OF SPACES AND SERVICE SYSTEMS
SPACE PROGRAM
PERFORM LIFE-CYCLE COST ESTIMATION
COST SPECIFICATION BY AN OWNER AND AN USER
DESIGNS OF SERVICE SYSTEMS
CLIENT
DESIGNER
OWNER
USER

Fig. 1: Simplified activity model (IDEF-0) of the life-cycle cost estimation method

Life-cycle costing can be applied from the very early need analysis design stages to the detailed design of building components. Life-cycle costing can roughly be divided in the following three design stages.

- analysis of functions, setting quality targets and level of energy consumption on the building level
- defining the building, its architecture, quality and functional targets on the system level
- building design on the component level

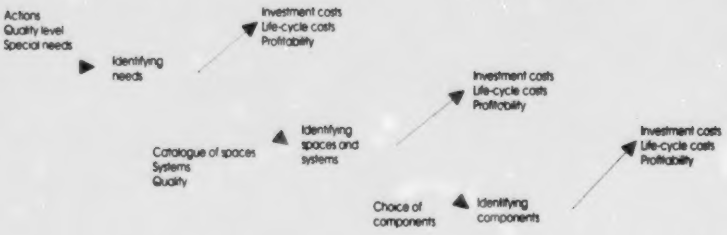

Fig. 2: Iterative life-cycle costing on different stages of building design

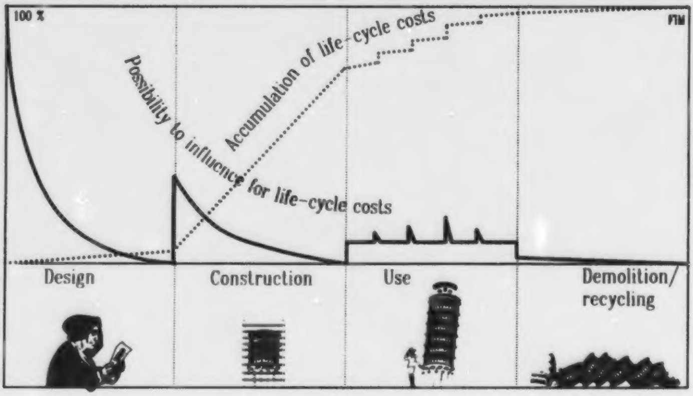

Fig. 3: Most part of life-cycle cost are fixed in early design stages

In this work the existing Finnish Space-Based Cost Estimation method is complemented especially with the maintenance cost factors of technical systems (HVAC and electrical) and the costs of these are divided for spaces. Occupancy costs will be reported from the viewpoints of a building owner and user. Also recommendation for a new indexing system for control of occupancy cost are under development.

2.1 Life-cycle costing models and tools for building service systems

During years 1993-1994, Granlund Oy developed models and prototype tools (HVAC) for the management of life-cycle cost of building service systems. By developing these models and tools further, it is possible to produce real software tools for different design stages and also devices to support decision-making in building maintenance. The central improvement areas are further development of price-list and consumption databases, integration of energy calculation software, definition of methods describing how to divide cost of service systems for spaces and development of a tool for electricity works management. The final objective is a software package including all the previous mentioned properties for comprehensive management of a building's life-cycle cost.

A standardised classification of maintenance cost has been published in Finland (Appendix 1, Figure 1). The main purpose of this classification is to make it easier to assign different facility management cost in a systematic way, draw up budgets, control maintenance costs, conduct accountings and understand the meaning of maintenance cost in connection with building planning. In this project we have interviewed Finnish real estate managers to clarify if they use this standard classification and what kind of further development needs they see in it. This project will recommend of new classification system for occupancy cost control. Life-cycle costs are reported according to this new classification and separated as cost of a building owner and a client.

3 Life-cycle model of facility management

Life-cycle cost consist of investment and maintenance (care and renovation) costs. In Tila-Suku facility management software developed by Rapal Oy, investment and maintenance cost are defined per space unit.

Investment cost are allocated by space based on the Target Cost Method of the Finnish Building Cost Information System. Investment cost are transformed to annual cost with the annuity method. Then investment cost are comparable with the maintenance cost.

Maintenance cost are calculated with the help of the actual real estate maintenance cost information book published by the Building Economy Laboratory of Technical University of Helsinki. Consumption of heat and electricity, unit rates of cleaning works and renovations are allocated per space unit. Cost items which are not based on unit rates are allocated as space and client based (e.g. building managing, services, water, special equipment service, insurances, waste service) are divided for spaces by their areas.

The resulting target prices and maintenance costs are calculated. Generally information of actual cost are obtained in the form of total cost by cost items. In Tila-Suku the actual cost can be allocated for the spaces by calculated cost. Then for example rent or profit of each space can be estimated by investment and maintenance cost of this space.

4 Recommendations

The LCC-model and tool presented in this paper can be applied in various supporting tasks. The model can be used to develop computer-based tools for specific knowledge areas. Some kinds of tools are in use in different countries but much research work is still needed.

The recommendations are as follows

- we should develop a standard for LCC-model to be utilized in co-operation with different countries world-wide
- the model should cover spaces and technical systems
- the analysis should also include the analysis of the most important environmental effects on chosen technical systems
- the model must be independent of the information technology used in different countries and companies

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Appendix A

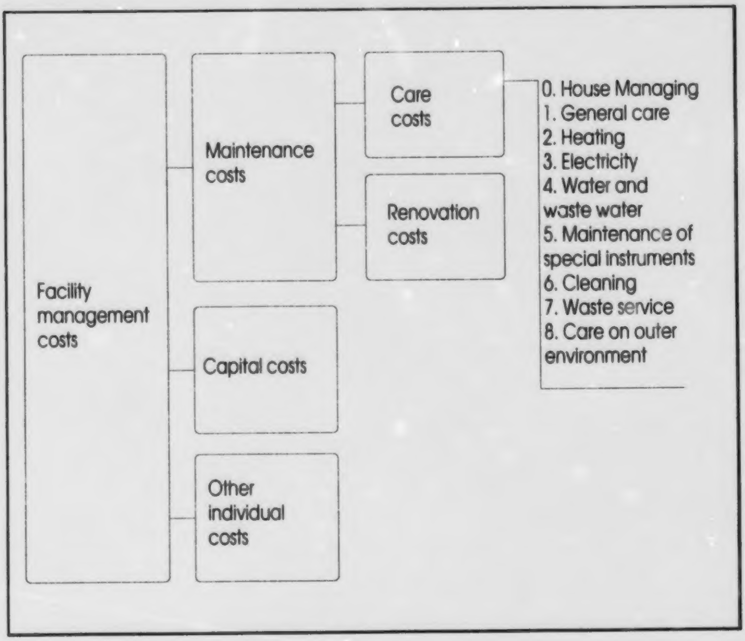

Fig. 4: The official classification of Finnish facility management cost

261 INTEGRATING PERMANENT EQUIPMENT TRACKING WITH ELECTRONIC OPERATIONS AND MAINTENANCE MANUALS

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Abstract

Permanent equipment may be delivered months in advance of installation on a construction project. It may be received, stored off-site, transported to on-site storage, installed, and tested. During construction, there are obvious advantages to knowing where each piece of equipment is at any given time. During operation, the owner of the project needs to know the status of equipment during operation and be able to find the proper operating and maintenance information when required. We have completed a trial system on a wastewater treatment plant project that uses bar codes to track equipment from receipt to installation, and then is used to interface with an electronic operation and maintenance (O&M) manual. The O&M manual can be accessed in a variety of ways, including bar codes on the equipment, selecting the equipment on electronic drawings, and pointing and clicking on digitized photographs. The interface to the electronic O&M manual can be a valuable added service to the owner.

Keywords: Bar codes, construction, information technology, data collection

1 Benefits of bar code tracking

Bar coding is incredibly fast and error free compared to standard keyboard entry of data. With a laptop or smaller computer, it is possible to have an encyclopedia of information immediately accessible. With bar code technology, one quick scan can perform complex computing operations or yield instant access to information on particular equipment such as location, status, specifications, submittal data, etc. For example, a construction superintendent in the field would need only to turn a

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notebook computer on, scan a bar code, and end up logging current time, location, site conditions, or even pinpoint a certain item in a huge database and review the appropriate specifications or specification manual.

Manufacturing companies recognized the potential for increased production using bar codes over a decade ago. Bar coding is often the primary foundation to computer automation of manufacturing. A bar code system integrated with automated material handling helped General Electric reduce the manufacturing time of aircraft engine components by 30% and boosted productivity by 50%; boosting production from 207,000 units to more than 320,000 units with essentially the same work force (Pashall, 1986). Additional benefits included reduced cycle times, reduced work-in-progress inventory, and nearly perfect work-in-progress tracking accuracy.

Merchandise distribution companies also recognize the potential of using bar codes for increasing production capacity. As Elizabeth Arden's business grew, the traditional solution for increased capacity was to add more workers at their primary distribution center in Roanoke, VA. However, the faster the workers picked merchandise for shipping, the longer it took to get orders out the door (Field, 1997). Bar coding proved to be the core of the solution. A Code 39 bar code is automatically assigned to each order the moment the order is taken from the customer. Bar code scanners are strategically placed along the conveyor system, from empty carton stage to the end of the dock, as well as on all forklifts, for permanent tracking through the entire process. Radio frequency (RF) communication with all scanners permits real-time tracking of all cartons as well as real-time inventory management from any terminal in the facility. Bar coding permitted the use of an automated picking system, automated conveyor sorting, and an automated weigh-in-motion system.

Benefits for Elizabeth Arden were tremendous: a 24 hour operation was reduced to 8 hours a day, with a reduction of full-time work force from 180 to 120 employees for the same workload. During the peak season, the temporary work force was reduced from 150 to 30 employees. The $3 million system had a two-year return on investment. Over 3,000 customers can now expect same-day shipping perfume goods where before it was often a week or more, enjoying virtually 100% shipping accuracy. Elizabeth Arden now has immediate visibility in inventory control because of radio frequency and bar code systems.

2 Bar codes in construction

The Construction Industry Institute undertook a study of bar code applications in construction (Bell and McCullouch 1988, Bell and Gillis 1989). A review this work is not possible here, but it forms the foundation for this project. Many others have published work in the application of bar codes to construction as well. This paper presents one application.

Many large construction companies are using bar codes to manage aspects of their work. They see the reduction in potential for errors and the speed of entry as the primary benefits. Included are Fluor Daniel, M. W. Kellogg, Bechtel, and H. B. Zachary; focusing on areas such as small tool tracking, time and attendance, structural steel tracking, materials management, and workflow.

With the recent increase of commercially available and user-friendly bar code systems, small and medium-sized construction companies can take advantage of bar codes in managing their work. In the fall of 1996 the Virginia Tech Construction Affiliates, a partnership between Virginia Tech and a consortium of construction companies, became interested in studying field data acquisition applications. A significant portion of the resulting Field Data Acquisition Project was permanent equipment tracking, with an effort to apply existing bar code technologies to applications in the construction industry.

Permanent equipment tracking is particularly suitable to the design and construction of wastewater treatment facilities. State regulatory commissions are stringent on operation and maintenance (O&M) requirements of wastewater facilities, because a shutdown of a system could pose a serious health threat to a community of people. On typical construction projects, O&M manuals are compiled from submittal information from equipment manufacturers; submittals often end up on-site, at the engineer's office, at the contractor's office, etc. For wastewater facilities, the state regulatory commission requires that the engineering design firm for the project prepare and bind an O&M manual including all pertinent submittals, and certify that all facility information is included and accurate.

At the beginning of this study, Anderson and Associates, Inc., a member of the Virginia Tech Construction Affiliates, was managing the design and construction of the Fort Chiswell Wastewater facility in Wythe County, VA. Anderson was interested in taking the O&M preparation one step further and considering the possibility of providing an electronic O&M manual as a value-added service for the contractor and owner.

Potential benefits of an electronic O&M manual are numerous. During construction, the contractor could immediately know the location and status of equipment by taking a virtual site tour using electronic drawings, or scanning a bar code on a particular piece of equipment. During operation, the owner could access equipment information in the same manner, and review specifications, maintenance logs, or any other information that would be linked to the electronic tracking system. Likewise, the owner could go to a particular piece of equipment and scan a bar code and access with guaranteed accuracy the same information. Such information could help avoid common problems, such as ordering an incorrect repair part for a pump because of mistakenly reading the O&M specifications for the wrong pump, a potentially costly and serious mistake.

The scope of this project was to develop a PC based electronic tracking system using linear bar code technology and commercially available software. The first objective is equipment tracking during the construction phase. The second objective is to link the information to an electronic operation and maintenance system for the owner during the operation phase.

2.1 Permanent equipment tracking project

Selected site – Fort Chiswell Wastewater Project, Wythe County, Virginia. With the assistance of Anderson & Associates, Inc. and W. Rogers Construction Company, a 500,000 gallon per day wastewater treatment facility was used as a pilot project. The $3.3 million project was in the construction phase at the time of this study, and much of the equipment was still arriving to either the site or W. Rogers' warehouse, ideal for testing bar-code applications.

Bar code labels - Compliance labeling versus labeling at receipt – Compliance labeling refers to product suppliers complying with standardized bar coding labels on products as required by the customer. Many manufacturers and retailers require their suppliers to become electronic commerce trading partners: product must be bar-code labeled per specified guidelines prior to shipment to allow electronic shipment tracking and to coordinate product identification in the customer's database.

Compliance labeling was not considered in this project. Given the small scale of this project, such a requirement was not deemed necessary. Nor would it be practical since the construction of the facility was concurrent to this study. However, on a large project with a large inventory of equipment, or especially where materials such a fenestration goods have a wide array of sizes very similar in appearance, compliance labeling could be a real asset to electronic tracking. In this case, it was considered more rational to label equipment at time of receipt.

Code 39 bar code symbology was used for this study. Code 39 is the most frequently used symbology in manufacturing and industrial bar code systems (Lee, 1997). It allows a variable length code of any of the 128 alphanumeric ASCII characters and is an easily read code in terms of scanning.

A critical link in a bar code system is the durability of the bar code labels in the working environment. The harsh construction environment poses a serious threat to the quality of the bar code system, and continues during operation for a wastewater facility as studied for this project. If a label cannot withstand the environment, and thus cannot be read by a scanner, the bar code system is rendered inoperable. The focus of this study did not include label durability. Metal-etched bar code tags along with specialty products such as Bumpy Bar Code™ are commercially available, and a fair amount of construction research has focused specifically on label durability in the construction environment. It is worth noting here that label durability be a primary consideration when developing a permanent tracking system.

Equipment labeling - An initial challenge was being able to effectively label equipment, regardless of the location that it was received. Ideally, any location receiving equipment would have a bar code reader for automatic data input. Realistically, as may be expected on an actual project, equipment may arrive and a bar code reader is not accessible. The method chosen to accommodate varied conditions of receipt was to furnish an equipment receipt log, having paired labels beside of each entry. As a piece of equipment arrives on-site or to off-site storage, a bar code tag is placed on the equipment. Data is then entered directly into the database if the bar code system is available. Else, data is entered in the log next to the remaining identical bar code label, or the remaining label is peeled off and placed on the equipment invoice for keyboard data entry.

There were several advantages to this labeling method. For the small size and relative complexity of this project, it was not deemed necessary to have the bar codes coordinated with database entries prior to equipment receipt. Rather, as invoices are logged, bar codes could be coordinated at that time. Also, a metal etched label or other type of specialty label could easily be substituted for the equipment label for durability requirements.

Computing and bar code platform – Microsoft Windows® was chosen for the operating environment. Many construction companies are using Windows or NT for office personal computing, and especially so in field applications. Specifically, Microsoft Office® was used, providing powerful and economical capabilities for integrating bar coding technology with database and CAD technology. Microsoft Word, Excel, Access, or any other similar Windows applications are likely candidates for building an equipment database, and subsequently an electronic O&M manual. This is advantageous since most PC users seem to stick to one application, such as Word or Excel, and will give almost any excuse to avoid learning other applications. Further, without the integration offered in the Windows environment, bar code systems usually require extensive custom programming, which is cost prohibitive in small-scale bar code systems as proposed herein.

The Wasp Nest® bar code package, by Informatics, Inc., has several features that were desirable for this project. Wasp Nest is a professional bar code scanning and labeling package designed to integrate bar coding into any Windows based applications. This package can turn any personal, laptop, or handheld computer into a complete bar code system in minutes. Labels can be generated, scanned, and decoded for all popular bar code symbologies. Labels can be printed using ordinary laser or ink-jet printers. Very little training is required to be quite proficient for users familiar to the Windows environment. Current costs for a one-user package range from $200 street price for complete package with economical wand scanner to $600 street price for same package with laser scanner and support for two-dimensional scanning. The package with wand scanner was used in this study. With built-in remapping features, bar coding can be powerfully integrated into tracking with little or no additional Visual Basic® programming required.

Visio Technical® provided a powerful means of integrating bar coding and the database and AutoCAD® site drawings together. The actual AutoCAD site plans were imported into Visio. Features that make Visio unique for this application are that custom shapes can be created that have built-in intelligence; an intuitive interface for linking to the bar codes and database information simply requires a good understanding of the Windows environment; advanced tracking capabilities can be performed if the user is adept with C, C++, or Visual Basic for Applications. Working drawings can be imported from any of the popular CAD software packages, and are fully editable. The result is that "smart" shapes can be created on actual site or building plans which can be linked to virtually any application that is Microsoft ODBC (Open DataBase Connectivity) compliant. In this case, a "smart" shape is created and placed on the drawing where each piece of equipment is currently located on the site. The shape is then hyperlinked to the desired information in the database for status, location, specifications, or other desired information.

Computer – A Toshiba Pentium 120 notebook computer was used in this study, being portable, relatively fast, and having ample storage capacity. It was readily available and was a good fit for this project. The computer was loaded with the required software, and outfitted with a wand scanner.

One concern in using this setup was durability of a notebook computer in the construction field. A common criticism for computers in the construction field is lack of resistance to the harsh environment, especially from being dropped onto the ground. It is worth noting that the initial intention for field use was to use a portable data terminal similar to, but more rugged than what United Parcel Service (UPS) and Federal Express use. However, a sales associate for a prominent bar code manufacturer said that admittedly, bar code equipment has not been developed to date, by his company, that is intended to meet the rugged requirements of the construction field. And so, considering the ability to integrate all of the commercially available components using the Windows platform, along with the power of having a complete database with intelligent electronic drawings, a notebook computer was considered to be the best option.

2.2 Using the bar code system

The initial step on the construction site was to bar code label permanent equipment. Bar code labels were affixed to equipment stored on site as well as several pieces already installed. Digital photographs were then taken of each piece.

At the same time, the electronic layout was taking shape in terms of tracking software for the contractor during construction. The site and building plans for the project, in AutoCad® Release 13, were imported into Visio Technical in fully editable format. Some extraneous information was deleted to optimize processor speed. When equipment was bar code tagged, a smart shape was also created on the electronic site plan, corresponding to the current location. The bar code decoder was remapped so that when scanned, the particular bar code would direct the user to the location on the site plan. By hyperlinking the smart shape, a powerful feature of Visio, the user selected the shape and was directed to a page with digital photograph of the equipment, current status, and related specifications. An important note is that the shapes can be linked in the same manner to any ODBC compliant applications desired.

In practice, while the contractor is using the electronic layout for construction tracking, the design firm would be building the electronic O&M manual on the same electronic framework. Some manufacturer's operations and maintenance manuals are available on electronic media. Other submittals received in paper form, would be digitally scanned into an ODBC compliant application, such as Microsoft Word, Excel, or Access.

For the O&M manual, smart shapes were hidden where the permanent equipment was shown on the plans. The bar code decoder again was remapped so that a bar code scan directed the user to the piece of equipment on the electronic plans. This configuration yielded a twofold result: a plant operator could directly scan a bar code labeled piece of equipment, and would be directed to the plans to confirm a correct scan. Second, the operator could access the electronic drawings on the computer, and select the same piece of equipment from a remote location. From that point, selecting the shape would direct the operator to a digital photograph, corresponding O&M information, maintenance log, etc.

This project resulted in several significant implications. The cost of the software and bar code equipment was on par with any other software used in the typical office, and the cost of the computer basically depends on the level of compactness and performance desired. Anderson & Associates, Inc., being the design firm responsible for delivering the O&M manual, is highly computer oriented in their work, as are most design firms. The implication is that an electronic O&M database containing drawings, specifications, O&M, photographs, and even video imaging could be powerfully integrated, and delivered to the contractor and owner without great effort beyond what is already required. Further, this electronic package could be supplied on CD-ROM. This could be a value-added service, with opportunity for being paid services that are of value to the contractor and owner.

3 Conclusion

Using the Wasp Nest® bar code package, along with Microsoft Office® and Visio Technical®, a bar coded electronic O&M manual was developed. The user can scan a bar code label that is attached to a particular pump, motor, etc. and access assembly diagrams, specifications, and log repair/maintenance data. The AutoCAD® site drawings were also linked to the O&M manual. In this manner, the user opens the computer files of the site and building plans, selects the particular item, and accesses the same information while sitting at a remote location.

An important conclusion is that a database containing drawings, specifications, O&M, photographs, and even video imaging could be powerfully integrated using CD-ROM technology. This system, including costs, could be incorporated into a project at the planning stages, and carried throughout to project completion and into operation, with all parties using the same information.

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262 THE DEVELOPMENT OF INDUSTRY FOUNDATION CLASSES FOR FACILITIES MANAGEMENT

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Abstract

The Industry Foundation Classes (IFCs) are integrated object models of building projects developed by the International Alliance for Interoperability (IAI). The IFCs support data sharing and exchange between industry processes across multiple domains such as architecture, structural engineering, building services, construction and facilities management (FM).

Maintenance management is one of the major functions in FM. It requires object information about building systems and components that are generated from different domain processes throughout different stages of the project development life cycle. Supported by the IFCs, this information can remain available until the building operation phase for maintenance processes to use. However, this information requirement must be defined based on detailed analysis of maintenance processes, and must be modeled using a formal modeling methodology, that is, the IFCs.

This paper describes the current and proposed developments in facilities management in the IAI, particularly for maintenance. It also discusses a planning 'roadmap' that identifies discrete packages of information that support FM processes.

The paper demonstrates a general maintenance process model developed to define the object requirements and interfaces for sharing maintenance information. Based on the process information analysis, the paper develops and presents a set of IFC object models that support the maintenance processes. Additionally, this paper discusses the necessities and capabilities of the IFC maintenance objects to access and utilize external information provided by various library resources.

Keywords: data modeling, facilities management, International Alliance for Interoperability, Industry Foundation Classes, maintenance management

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1 Introduction

Facilities Management (FM) is at least as important as design and construction within the overall scope of the building construction industry. This is particularly so in developed countries where growing interests in the conservation of the building stock, management of energy use, social and environmental factors play a large part in determining development policy. Refurbish and maintenance business can account for nearly 50% of the annual revenues in building construction in some countries and it is probable that this figure will increase.

Most of the effort that has gone into the development of models for information exchange and sharing in building construction to date has been focused on design with a limited (but increasing) effort in the construction process. Little effort has yet gone into facilities management. In this respect, building construction is in the same state as other industry sectors such as process engineering and shipbuilding.

Within the International Alliance for Interoperability, there has been recognition of the increasingly important role of the Client and Building Owner as an actor in the overall building construction process [CB1 1998]. The Client/Building Owner (called the Client in this paper) is the actor for whom a building must fulfil its intended function and who pays the bills for ensuring that it does so. Client members of the IAI show a keen interest in the development of Facilities Management models and have driven this to become one of the key development areas for Industry Foundation Classes (IFCs) [IAI 1998a].

In this paper, the role of facilities management within the IAI [IAI 1998a] will be discussed and the development of the IFCs to meet facilities management needs explained. In particular, the development of a model for engineering maintenance will be presented and the objectives for the future development of this and other FM models considered.

2 Positioning the FM process

Whilst this paper emphasises on FM, it recognises the roles that are played in the information lifecycle by the requirements, design and construction processes (See Figure 1). Each of these has the role of information provider to the downstream process and, ultimately to the FM process. The state of the model following each process is of interest to the FM process in which the facilities manager 'operates and manages' the facility. For many highly technical buildings, the process of demolition and the maintenance of information to enable demolition is increasingly important and should be included as a high level process.

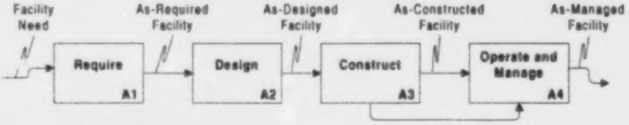

Fig. 1: Positioning the FM process

Facilities management is also important as a provider of information to other processes whether within the same facility or as a historical basis for other facilities. The importance of this is being recognised in the work on design feedback [BSRIA 1998]. Feedback is also important in the refurbishment of existing facilities. Where information on facilities operation and management is maintained, the need to 'discover' the existing situation by survey is reduced with a consequent benefit in design cost and a reduction in risk cost. Risk, as will be seen later, is a key factor in the business benefit of a FM model.

3 Lifecycle considerations

Buildings and engineering installations have a long life cycle. However, many of the components that go into them require maintenance and periodic replacement. Computer Aided Facilities Management (CAFM) systems have the capability to store maintenance histories. There are potential benefits to being able to share this information so that better evidence for investment decisions is available.

Within the United Kingdom, there is growth in the number of 'Design-Build-Operate' projects in which the responsibility for the entire facility rests with a single source, the revenue coming from payments made periodically by the building owner. Unlike projects that do not have an 'operate' component, life cycle costs can acquire significance in the profitability of the overall contract. It may be relevant to invest more in the relatively short 'Design-Build' component to use higher quality components and achieve a higher quality facility and to reduce the operating and maintenance costs as a result.

In the case of such projects, investment decisions may be made on a 20-30 year revenue expectation and not on the short-term capital costs of construction. Availability of life cycle information is crucial both to initial and ongoing investment decisions [Wix 1998].

4 Features and benefits

Traditionally the benefits of data exchange have been identified as a reduction in the amount of time that has to be spent re-keying data and minimisation of the risk of error that is inherent in such re-keying. Recent work within the FM group of IAI UK did identify this as a benefit but saw it as secondary to the reduction in risk that availability of information made possible. Table 1 lists the features of an interoperable FM model and the business benefits that can result from its use.

Continued work on the benefits of information exchange increasingly understands the reduction of risk. Frequently, this is equated with inherent quality built into 'intelligent and appropriate' information exchange. In a recent interview, a structural consultant identified a cost reduction of approximately 30% on a steelwork project directly attributable to increased quality and reduced risk. This 'hard' evidence, isolated though it still is, suggests that the expectations of Facilities Managers expressed above may be conservative.

Table 1: Features and benefits of data exchange

Features	*Benefits*
1. Operating and Maintenance information can be captured during project design and construction stages.	Reduces cost of asset list creation.
	Reduces the requirement for inspection visits and information gathering by the owner/operator after project hand over or by a maintenance contractor prior to taking on or taking over a maintenance contract.
2. Greater certainty that operating and maintenance information has been fully captured as it will not be missed or hidden during inspection visits.	Reduces risk in delivering the maintenance service. Risk value may be as high as 10% on a new project and, for comprehensive maintenance on an existing project it may be from 15% to 40% depending on age, condition and other factors. It is estimated that with higher quality and more complete information, the risk value can be at least halved without affecting profitability for the maintenance contractor.
3. Details of items requiring maintenance are complete at project hand over including item specification and supplier.	Reduces cost of order/invoice development for the client on shared risk contracts.
	Reduces recurring annual cost of 5% - 10% p.a. that normally applies due to not having all required data.
4. Complete and certain information with reduced cost of risk enables a maintenance contractor to provide an improved service at lower cost with equal or better profitability.	Increases the competitiveness of the maintenance contractor.
5. Access to operating and maintenance that can be directly incorporated into or referred to by maintenance management systems.	Accuracy of information will lead to better maintenance and improved maintenance scheduling.
6. Access to industry standard information that can be directly used for creating work orders.	Use of best practice information agreed on an industry wide basis will lead to improvements in the quality of maintenance work done.
	Best practice information will include for assessments on spares, tools, consumables and labour use that can lead to improved maintenance scheduling.
7. More complete and better information available during operation and maintenance.	More extensive queries and reports can be made that can lead to better analysis of the lifecycle and reliability of items being maintained.

5 FM scope and road map

There are many aspects of building operation that a facilities manager takes responsibility for. Some of these benefit greatly from the use of an interoperable FM, others less so. Within the IAI North America FM domain committee, typical FM functions have been identified including maintenance operation, property management and services (See Figure 2), acknowledging that all these identifiable FM functions have the fundamental characteristics of general project management functions such as scope, cost, time, work and risk management [Yu, Froese, and Grobler 1998]. A similar research by the IAI UK FM committee has come up with a similar FM function list.

6 Key maintenance processes

The IAI Engineering Maintenance project [IAI 1998d] identified a number of key processes: Identify Asset, Plan Maintenance, Do Maintenance, Record Maintenance, Use Maintenance Libraries, Purchase Equipment for Maintenance, and Account for Maintenance Costs (See Figure 3). A high level IAI project planning diagram was also developed that enables a series of maintenance processes to be identified for initial work whilst others will be subject to further development once the basic requirements are met (See Figure 4).

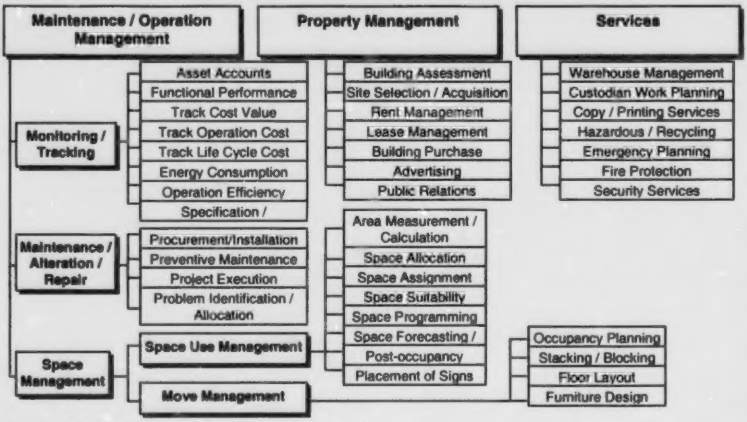

Fig. 2: Identifiable FM functions

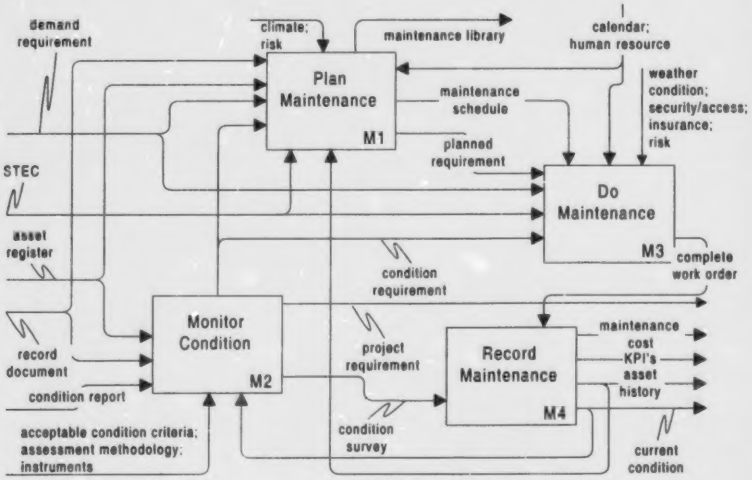

Fig. 3: Maintenance process model

7 Key maintenance concepts

Two key concepts are identified in defining engineering maintenance processes:

- The asset: i.e. a valued object on which maintenance work is to be performed.
- The work order: i.e. a contract, agreement, or request for the execution of the work.

An asset may be either a singular object or a group (or aggregation) acting as though they were singular (See Figure 5). In this case, 'singular' means for the purpose of maintenance work. From the point of view of an object model, an asset is similar in nature to any other grouping that combines to form an aggregated class. For instance, cost elements contain the idea of groups of things that have a single cost whilst a process may comprise a number of work tasks that have a single duration for completion of work. Similarly, an asset may be composed of individual component parts that require specific maintenance tasks. This idea of assembly is supported by the provision of a template class for the nesting of components within an assembly supported in the IFC Object Model [IAI 1998b].

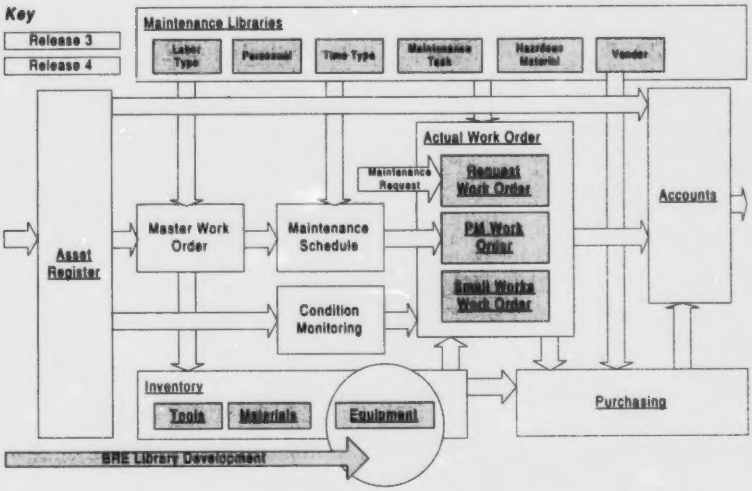

Fig. 4: IAI project planning road map for engineering maintenance

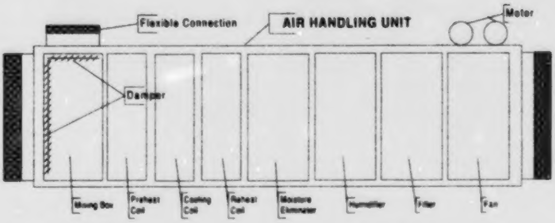

Fig. 5: An asset with grouped components-an air handling unit

The work order is explained above as expressing a contract between the issuer of the work order and the performers that carry out the process of maintenance. Although it may not be considered as a contract in the conventional sense of the term, it does in fact exhibit all the appropriate characteristics as follows:

- It has an author and a performer.
- It specifies work to be done.
- It specifies a deliver period.
- It identifies the skills and leadership necessary from the performers.
- It is uniquely identifiable.

Although the work started out on the basis of engineering maintenance, it has become clear that the identified ideas and processes apply to any work that can be construed as 'maintaining' that incorporates the ideas of an asset as something of value and that includes the issuing of an order to do work.

8 Maintenance planning

Initially, the sole objective of the project was to support the development of master work orders for planned preventive maintenance. A master work order acts as a template from which individual work orders can be created as needed. In looking at this topic, the possibility that standard data for work orders could be provided become apparent. Using the data requires either that an IFC work order class is structured so that it can accept the data or that an IFC property set is declared such that it can be bound to the model at runtime. Figure 6 shows an IFC model proposal for master work orders using simplified EXPRESS-G diagram.

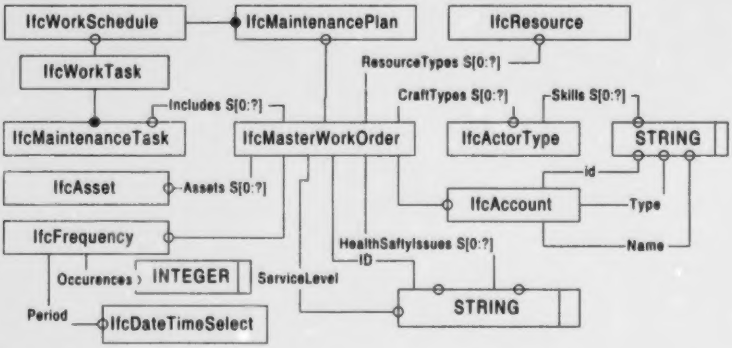

Fig. 6: IFC master work order

9 External library access

The use of the IFC property sets [IAI 1998b] is currently considered as the most relevant approach for external access of maintenance required data. Figure 7 depicts the basic state procedure of an external library access based on IFC models. However, the capabilities of this facility within the IFC Release 1.5.1 model are not sufficient [IAI 1998b]. In particular, the ability to reference a populated property set instance externally is not available. Figure 8 shows a conceptual IFC model proposal to enable external library objects to be referenced in a project using IFC property sets where both referenced library objects and property sets are registered and their links are retained.

To thoroughly deal with this problem, a support project is under way with the Building Research Establishment (BRE) [Nyambayo and Wix 1998] to enable the IFC property sets to access to external reference libraries. Whilst this is specifically targeted at maintenance information, it is potentially useful for any kind of information held externally.

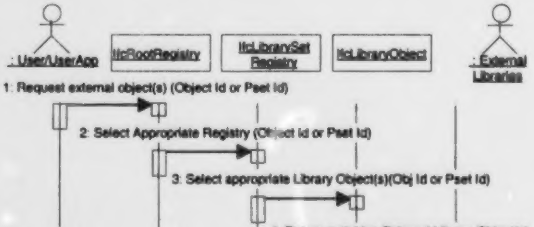
: User/UserApp
IfcRootRegistry
IfcLibrarySet Registry
IfcLibraryObject
: External Libraries
1: Request external object(s) (Object Id or Pset Id)
2: Select Appropriate Registry (Object Id or Pset Id)
3: Select appropriate Library Object(s)(Obj Id or Pset Id)
4: Return matching External Library Object(s)

Fig. 7: External library access state procedure

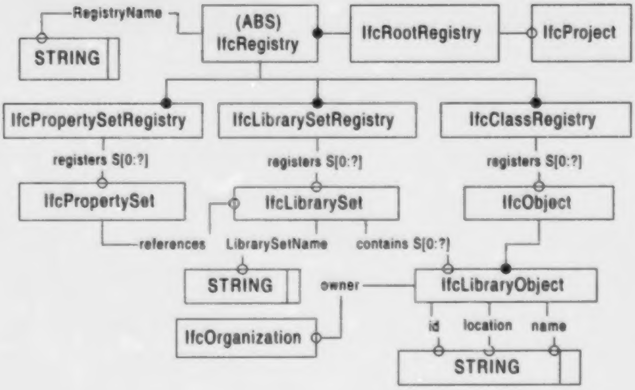

Fig. 8: IFC proposal for external library access using property sets

10 Demand maintenance, condition maintenance and small works

Even in best planned preventive maintenance programmes, a significant proportion of the work will be demand. Therefore, the model resulting from the project must also be able to accommodate work of this nature. Equally, maintenance programmes may be dictated by the current condition of assets. This could be termed "If it ain't broke, don't fix it" approach.

The condition of an asset may be such as to enable maintenance work to be planned or it may give rise to demand maintenance. Recording of condition is a vital tool in determining life cycle costs since it enables the application of predictive methods. Particularly important as a basis for the production are performance indicators, when the value of a given performance indicator may be used to trigger a maintenance event. At this stage, the project recognises the existence of such indicators but further work is required to establish the range of indicators that should be used.

Performance indication and life cycle considerations are important in determining when continued maintenance of an asset is no longer the most cost effective approach. In this circumstance, replacement is the more appropriate option and may be associated with other improvements as a 'small works' project. Whilst 'small works' is out of scope of current model development, its potential has to be recognised by a maintenance model so that feedback information can be used.

11 Design, construction and maintenance relationships

The advantage that interoperability offers is that project information, once created, remains available for any other process. For a project, we might express a hypothesis on 'conservation of information' such that:

> ***'Information, once created, is not destroyed but can be used and transformed for other purposes.'***

That is, information has a 'value entropy' in that, the further a project develops into its lifecycle, the more valuable the information becomes; it never becomes less valuable. The hypothesis can be demonstrated by Table 2 on an air-handling unit through principal life cycle stages. Thus, a key to reducing risk in maintenance is for maintenance applications to inter-operate with design and construction applications that understand the need to capture and make available relevant information.

Table 2: Design, construction and operation

Design:	Establishes a design parameter and sets down requirements for the configuration and performance of the air-handling unit. Even at this early stage, knowing the type of air-handling unit, the basic requirements of planned maintenance can be established.
Construction:	Selects the air handling unit to be used and places it in position. This adds specific information about the unit including manufacturer details that can be added to the more generic information from design. After generic information from design. After commissioning, the actual performance of the unit can be established and confirmed against design parameters.
Operate and Maintain:	All basic information requirements are available including warranties, parts requirements. Information about the maintenance performer can be added along with financial reporting.

12 Future work

This paper has focused on a number of concepts that are relevant to the development of conceptual models for FM in general and maintenance in particular. This is not a complete picture since what is presented is work in progress. FM consists of much more than maintenance as has been demonstrated and the IFC Object Model does already support some other processes. The range of coverage has to be extended and integrated.

Development of the maintenance model benefits from all of the known capabilities of STEP [ISO 1994] based modelling approaches and equally suffers from all of the well know limitations. Whilst developing models for static information exchange in the manner that is currently possible (and extending the potential via the use of IFC property sets) there is a need to develop a behavioral model and define the software interfaces that enable information sharing in a client-server environment. For this purpose, the project will be looking at the use of the Unified Modeling Language [UML 1997] as a potentially more effective way forward.

The maintenance process as it is being defined for IFC Release 3.0 is not complete. As the move is made to consideration of Release 4.0, the extent of the process will be extended and the degree of integration with the Reference Process Model of the IAI Client Group tightened. In particular, the work on Library development will be developed and work on aspects of financial reporting included. This latter item will have particular importance in connection with work on contract management and control.

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PART TWENTY

PRODUCT MODELING

PART TWENTY

PRODUCT MODELING

263 EXAMPLES OF PRODUCT MODEL TRANSFORMATIONS IN CONSTRUCTION

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Abstract

This paper discusses the results of a case study of product model transformations and geometric reasoning techniques for a challenging project. The complex geometry in the Experience Music Project offers unique challenges in construction processes. Manual transformation of the design-centric product model prepared by the architect into a production model for construction is time-consuming. We discuss ways to transform a design view of a product model into a construction view emphasizing the value of product models supporting multiple views. Geometric reasoning aids in the planning, scheduling, coordination of the project, and modeling of temporary structures. We are developing methods to support these product model transformations using the geometric model.

Keywords: Geometric reasoning, integration, multiple views, product modeling

1 Introduction

There has been a great amount of research in product modeling and symbolic reasoning for construction in the last decade. The results are gradually put into action. With the advent in product modeling techniques, uses and value of 3D CAD systems are increasing. Besides, advances in CAD/CAE systems make it possible to design more complicated structures that once seemed impossible. However, there is still a gap in the interface between the design and construction views of the product model. Most of the research efforts have focused on the design-centric view of the project, rather than on how it evolves during the project life cycle.

We have defined product model transformation mechanisms to transform

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design-centric product models into production-centric models (Fischer et al. 1998). Product model transformations provide the tools that make the product model a living electronic model of the project. Our ongoing research elaborates the requirements for product model transformations by defining the necessary representations for multiple views and geometric reasoning techniques. Once a product model with transformations is defined for a project, it supports the exchange of design information, enables 3D and 4D visualizations at various levels of detail, automates quantity takeoff and duration calculations, and so on.

This paper starts by describing the case study project. Next, by elaborating on the product model for the case study, we illustrate the transformations necessary for construction projects and the requirements for the representation of the product model. Finally, we explain the geometric reasoning mechanisms necessary to perform these transformations.

2 Motivation for product model transformations

An increasing number of design-build projects, as well as challenging architectural design and construction methods, require complex product model representations and transformations. One recent example is the Experience Music Project (EMP) in Seattle.

Construction of this structure is challenging in several aspects. The exterior is formed by sculpture-like surfaces with variable curvature in all three dimensions. The skin on the Experience Music Project consists of reinforcement, shotcrete, waterproofing, insulation and exterior steel plates and is supported by curved steel ribs. These ribs are in turn braced with secondary steel and support reinforcing bars. Figure 1 shows the components of the 3D CAD model. The complexity of the skin surface requires the contractor to apply several methods of construction at different locations. The project site is located in a bounded area near the center of the city. There is only one entrance to the site, which creates a significant accessibility problem. The site is congested, and laydown areas are quite limited.

The 3D CAD model is the basis for the construction documents at the site. The designer developed some unconventional 3D surface models of the buildings. This geometric information is sent to the construction site. However, the representation is not sufficient for construction. The general contractor has the primary responsibility in managing the data flow and distributing the information to the subcontractors. The interpretation of the CAD model is time-consuming. Participants do not have an automated method for creating their own product model view and updating it in case of a change, which makes it difficult to achieve a consistent data flow.

A design-centric product model alone cannot support the concurrent design and analysis necessary to develop an efficient and safe approach for construction. The designer develops the skin-surface model of one of the building elements shown in Figure 1. The CAD model of the skin includes the interior and exterior surfaces of the shotcrete, material properties and dimensions. Since no reasoning tools exist, the use of this model on the construction site is limited, namely to observe the shape visually and to check for interference with the temporary structures.

The left side of Figure 2 shows a cross-section of one of the building elements of the EMP. It shows how the construction operation varies depending on the curvature of the skin and the distance from the edge of the building. In nearly vertical areas near the edge of the building (1) workers will install the reinforcement and shotcrete, i.e. spray-on concrete, from scaffolding. In steep areas in proximity to the edge of the building (2) workers will use platforms cantilevered from the scaffolding. In almost flat areas (3) workers will work with tie-off to the structure. In steep areas away from the edge of the building (4) workers will need additional scaffolding and tie-off to perform the work. Each of these construction methods has different resource and space requirements and has different production rates.

To plan the use of resources and space over time and to predict the duration of skin installation, the planners need to calculate the quantities of reinforcement and shotcrete from the 3D CAD model. Therefore, they need to break up the 3D CAD model into zones related to the four construction methods. There is a need for a toolset that allows users to break up a 3D CAD model in new ways according to certain criteria (in this case the curvature, the height and the distance from the edge). This toolset needs to reason about the geometry. The right side of Figure 2 shows a decomposition for the given problem.

Meanwhile, the structural engineer has a different view of the project, and is interested in the rings of shotcrete in his analysis for structural stability during construction. The shotcrete surface, therefore, has different geometrical representation in these views.

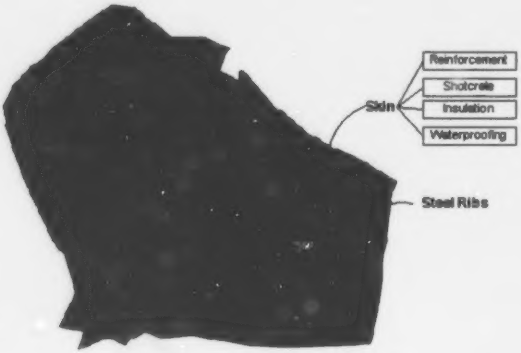

Fig. 1: Components of 3D CAD model for EMP element 7

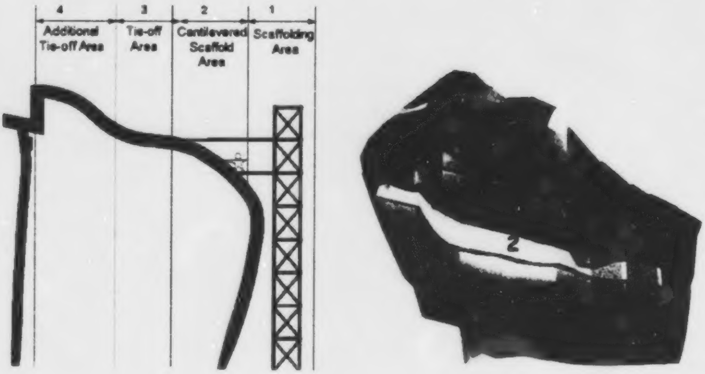

Fig. 2: Construction methods for Shotcrete in EMP element 7

Participants have interdependent objectives. The objective for the detailed structural design is to ensure structural stability when only part of the skin has been completed and the structure is loaded asymmetrically with wet shotcrete. The objective for construction is to allow the subcontractors to employ construction methods that lead to productive construction operations and a safe and efficient use of resources. A particular method, sequence, and speed of construction, in turn, might affect the structural reliability of the half-finished skin.

It is difficult to solve these problems without relying on the detailed 3D CAD model at hand. The need to generate alternative plans is remarkably high in this complex structure. Furthermore, it is hard for the project participants to achieve a common understanding of the construction methods. To satisfy these needs, we are developing the framework for product model transformations. In a fast-track project like EMP, there is a continuous need for product model transformations. Many researchers have emphasized the importance of transformations (or maps) between views (Jeng and Eastman 1998, Van Leeuwen and Wagter 1998).

3 Product model transformations

We have defined the typical mechanisms for transformations from design to construction, and illustrate them with examples from the EMP. The sample product model hierarchy in Figure 3 shows these transformation mechanisms.

3.1 Elaboration

This mechanism decomposes a single object into m objects (m>1). Elaboration is one of the most common transformation types from design to construction. In the EMP, the design-centric model represented the shotcrete surface as one object, i.e.,

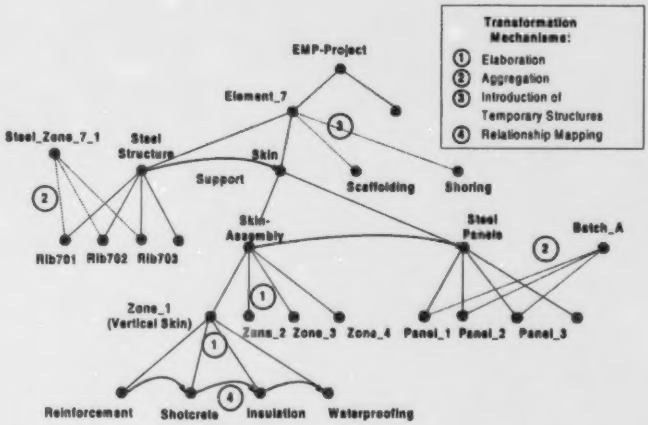

Fig. 3: Product model transformations from design to construction

a mathematical surface with the material information. The superintendent needed to plan the installation of the shotcrete in more detail. The activities he created would act on detailed skin components: reinforcement, waterproofing, insulation, and shotcrete. So he elaborated the product model accordingly. The breakup of a large component into zones is another example for elaboration type transformation.

3.2 Aggregation

In this mechanism, the components in the product model are combined to define new components. The architect designed the steel ribs as individual objects. The site superintendent, however, needs to combine a group of steel elements into one zone in order to accurately plan activities related to steel erection.

3.3 Introduction of temporary structures

Typically, temporary structures are not included in design documents or design-centric product models. However, they require resources for their installation and take up space for the duration of their use. Therefore, a construction planner needs to take the construction and dismantling of temporary structures into account when creating and evaluating a construction schedule. In the EMP, the general contractor created the shoring and scaffolding components using the product geometry and workspace constraints. Tools that create or configure temporary structures need to reason about the geometry as described in section 5.

3.4 Relationship mapping

The relationships between components can also vary in different views during the life cycle of the project. Whenever there is a change in the product model because of transformations, the underlying representations should be updated.

The planner needed to analyze the tolerance between the skin components to plan the installation sequence of the skin components. As the contractor elaborates the skin into components, the physical support relationships should be created automatically. We have implemented algorithms that can translate the relationships from design to construction using geometric reasoning.

Figure 4 shows our approach for product model transformations. Our research focuses on mappings from the design view to the construction view, although we are well aware that this is not the only possible transformation type. Since design always precedes construction, there is always a design-centric model before the other views.

4 Representation for multiple views

As the EMP illustrates, there should be multiple representations for certain components in the product model. Rosenman and Gero (1996) suggest that views should be able to represent a component with different composition hierarchies. Different graphical representations for a certain component will either have to be stored in each view, or need to be created with methods linked with that component.

It is widely accepted that AEC information should be represented in multiple views so that participants in a construction project can extract their views from the product model of the project and update the model after changes (Eastman and Siabiris 1995; Hannus and Pietilainen 1995). There have been various approaches to representing multiple views (Table 1). MacKellar and Peckham (1993) suggest that product models that support views can consist of a single or of multiple models.

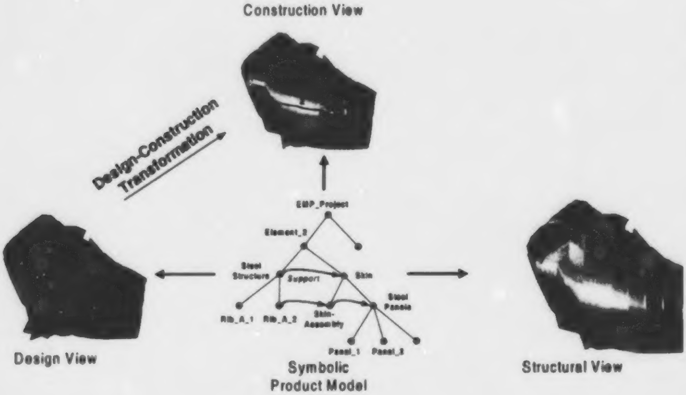

Fig. 4: Multiple view representation in the product model

Table 1: Approaches for multiple view representations

	Advantage	Limitation
Aspect Models (Van Nederveen and Tolman 1992)	Creates views from a single product model	Cannot change initial schema
P-C Approach (Howard and Phan 1995)	Provides methods to define product models and create multiple views	Fixed set of primitives No transformations
IFC (IAI 1998)	Provides a standard language for product models	No view definitions or transformations
EDM2 (Eastman and Siabiris 1995)	Provides database mechanisms for view changes	Limited to design phase

4.1 Static-schema models

Initial focus on multiple view representation has been on static-schema models. A schema is a template for a data model representation. Van Nederveen and Tolman (1992) define a kernel model and use aspect models to store view-specific information. The result is a set of models, each of which describes the building from a different viewpoint. They define the relationships between these aspect models. Although efficient during modeling, this approach is limited in updating the model, because it defines a static version of the product model rather than an evolving schema necessary to make the project information through design and construction.

The Primitive-Composite (P-C) approach (Howard and Phan 1995) is a data modeling technique that supports multiple views. Users define the primitives for the product model manually using a well-defined methodology. It is possible to aggregate the primitives to create composites. Using a selected set of primitives and composites, multiple views are created. However, the user needs to know beforehand how detailed the components should be, which limits the usability of the approach. In addition, each primitive can only have a single interpretation in this approach. Ongoing efforts towards Industry Foundation Classes (IFC) are standardizing the product model. However the IFC do not provide a mechanism for view definitions and transformations (IAI 1998).

4.2 Evolving-schema models

It is very cumbersome to map the product model manually on each a change in views. Consequently, there should be automated methods within the product model that support these transformations. The components of the product model should have methods that support not only the creation of new objects but also views of the product model that may differ in the level of abstraction and detail.

EDM-2 (Jeng and Eastman 1998, Eastman and Siabiris 1995) represents and supports translations between design views that evolve throughout the design process. Therefore, it is capable of model evolutions. A core model exists to reduce the number of maps required. EDM-2 is essentially a product database, grounded on a data model. It addresses fundamental database issues, such as the maintenance of data integrity; the defining of derivations and views; and the definition of a procedural language supporting model addition, deletion and modification. EDM-2 is implemented at the data level and does not, to our knowledge, specify operational transformations for construction.

5 Geometric reasoning

Figure 5 shows our geometric reasoning architecture. The user defines transformation rules and specifies items that create constraints for the system. Using the product model that is generated during design, the system reasons about the geometry to define the spatial relationships and extracts the features from the components to produce the construction view. The product model kernel is built on Industry Foundation Classes.

3D CAD models contain essential information to develop transformations. To transform between the different views of the product models, there must be efficient geometric reasoning techniques. The requirements for these techniques are the representation of spatial relationships between objects, the extraction of geometric properties and features, and the evaluation of constraints.

To decide on the layout for the shoring inside the structures of the EMP, spatial relationships between the shoring and the ribs, cranes and scaffolding must be represented. The layout is constrained by factors like the curvature of the ribs and workspace requirements. The structural engineer resolves the dimensions of the shoring and makes an update on the layout. At this point, the contractor needs to do time-consuming rethinking to evaluate the layout and consider its effects. Similarly, to decompose the shotcrete surface into zones, an automated system should consider the relationships between the scaffolding and the skin surface and the height and curvature of the skin. Construction process information affects the constraints. For example, the flow of work to install the skin is a constraint for the shoring layout.

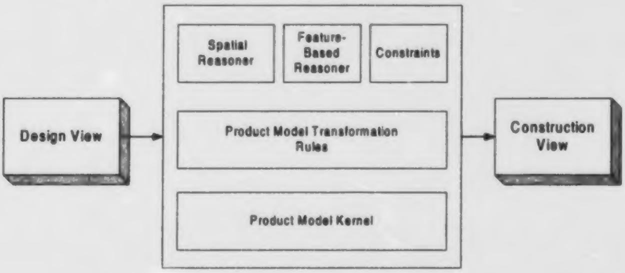

Fig. 5: Architecture for product model transformations

Previous research has defined techniques for geometric reasoning in different industries. For example, in the manufacturing industry, CAD systems are widely used as planning tools, as in assembly and process planning (McMahon et al. 1998).

The complex geometry of the parts and the assemblies are abstracted using features that store the product's important characteristics and associate them with engineering knowledge. Using feature-based modelers, or feature extraction algorithms, it is possible to plan and reason about the geometry of each feature. Ongoing efforts try to define a similar scheme for architectural design (Leeuwen and Wagter, 1998). We have tested the reasoning techniques used in feature extraction algorithms to reason about the properties of a geometric model.

In construction, the GRID research project developed a qualitative geometric-reasoner for spatial, temporal, and logical reasoning about 3D geometry (Chinowsky and Reinschmidt 1995). Qualitative spatial relationships are used to abstract the spatial relationships between components and reason about the geometric model (Clementini et al. 1997). Quantitative distances are converted to relationships like *after*, *on-top*, and *contains*. This directional information defined in one dimension is generalizable to multi-dimensional models. However, these research efforts simplified the geometry of the components to basic primitives, which is not sufficient for real world construction projects.

6 Conclusions and future work

This paper described ongoing research to define a methodology to transform product models from design to construction using product model transformations. We are focusing on geometric reasoning techniques needed for these transformations.

This research is a part of the effort to automate generation of 4D production models based on design-centric product models. We are implementing these mechanisms using the Object ARX development environment in Autodesk Mechanical Desktop and the Construction Method Modeler (CMM), an automated construction process planner (Fischer and Aalami, 1996).

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264 PRODUCT MODELING FOR CONSTRUCTION MANAGEMENT

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Abstract

With the ever-increasing use of computer technologies for managing the information involved in business processes, information standardization has been identified as an important step towards improving the efficiency and effectiveness of these processes. Over the past two decades, many research and development projects have worked towards standardizing existing information in the architecture, engineering, and construction (AEC) industry. Many information models at different levels have been proposed and many prototypes have been developed. The major part of this effort has focused on modeling product information in AEC projects (as opposed to process, organizational, or other project information), and has concentrated on the designer's perspective. Our interest, however, is from the perspective of project managers. Although project management introduces a spectrum of process information that governs the act of constructing a project, the product information that describes the facility itself is still central. Yet this product information is not explicitly represented in existing project management software such as estimating and scheduling software. This paper outlines the dimensions of a research project aimed at product modeling for project management. It discusses some of the specific requirements of product models for the purpose of supporting project management functionality. The paper also describes a framework that has been devised for categorizing project management functions.

Keywords: Construction Management, Construction Management Information Systems, Information Models, Process Models, Product Models, Project Management

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1 Introduction

Management of product information is attributed as a strategic action for achieving "process efficiency" [Leslie 1996]. Any architecture, engineering, and construction (AEC) project starts and ends with a product; i.e. starting with recognition of a need (for a physical object, as a product) and ending with the constructed product. In the evolution process of the product, from conceptualization to realization, information about each stage of the product becomes a stimulator and reference for subsequent processes. Therefore, defining, representing, and presenting this information in a shareable and exchangeable form is crucial to the smooth progress of projects.

The existing commercial project management systems, despite their coverage of many application areas, do not support a full range of construction management (CM) functions. Moreover, product data, despite its centrality for operations of CM functions, is not explicitly represented in the current systems. Human interpretation usually is a part of the processes of these functions. Thus a higher level modeling of such information has been sought. However, there seems to be different approaches to the development of such models [Fischer et al. 1995]. Moreover, the proposed product models tend to portray a designer's view in some specific aspects of the product and thus they are not as appropriate for supporting CM processes. There is a question of how to model product information in a way that the resulting models could be shareable among CM functions.

This paper provides an overview of our research, aimed at product modeling for project and construction management. First, a background is presented. A brief outline of the objectives and methodology of our research follows. The rest of the paper gives some of the visions of the research and a framework developed for classification of PM functions.

2 Background

2.1 Project and construction management

Grouping *works* performed by organizations into operations and projects, the Project Management Institute (PMI) defines the term *project* as: "a *temporary* endeavor undertaken to create a *unique* product or service." It then defines *Project Management* (PM) as "the application of knowledge, skill, tools, and techniques to project activities in order to meet stakeholder needs and expectations from a project" [PMI 1996]. More specifically, the term *Construction Management* has been defined as "*the composite of all modern project management methodologies having as their objective the control of time, cost, and quality in the design and construction of a new facility*" [Kavanagh et. al 1978].

For the purpose of this paper, we apply the term 'CM functions' to refer to the activities that take place in the delivery of a construction project. We relate these functions to those performed by the constructor of the facility, from preparation for construction to construction and hand-over of the product to the stakeholder (or owner). However, in some occasions, due to inheritance of the functions of PM by CM, we use these two terms interchangeably.

2.2 Product, product model, and process model

Though tightly interwoven, the totality of *project data* can be divided into *product data* and *process data*. The term *product*, in a materialized sense, is defined as: "thing or substance produced by a natural or manufacturing process" [Oxford Dictionary 1989]. This definition matches with the definition given in a data modeling sense, by ISO: "a thing or substance produced by a natural or artificial process" [ISO 1992].

Product data is also defined as: "a representation of facts, concepts, or instructions about a product or set of products in a formal manner suitable for communication, interpretation, or processing by human beings or by automatic means" [ISO 1992]. Some examples of product data are 3.00, large, SouthEast, and acceptable; representing the height (in metres), size, orientation, and finishing quality of a wall (i.e. product) respectively. Product data gives information about different characteristics of the physical product, irregardless of how it is built. A *Product model* describes such information. Examples of product-oriented models are RATAS [Bjork 1989], COMBINE [Augenbroe 1995], and STEP standards [ISO 1992].

Process data, on the other hand, is data about processes in a system; i.e. data about the actions taken in order to construct a building, for instance. It includes data on construction methods, resources, organization, etc. Process models describe such information. Examples of proposed process models are IRMA [Luiten et. al 1993], and ICON [Aouad et. al 1994].

The concept of *project models* [Fischer and Froese, 1996] is a response to the need for integration of product and process information. One of the major on-going standardization effort is the activities of the IAI (Industry Alliance for Interoperability), which is similar to the STEP project and has aimed at definition of building industry object classes called the Industry Foundation Classes (IFC's). IFC's are considered to be a library of commonly defined objects, creating project data, and supporting the whole life cycle of building development [IAI 1997]. Nevertheless, so far, the focus of this project has been more towards modeling design and facility management application areas, and defining those objects supporting construction management functions has been limited to estimating and scheduling.

3 Objectives and research methodology

The scope of this research is product modeling for Construction Management. The basic question of *how product model information can be useful for CM processes* has been split into the following four research issues:

1. What are the information ingredients of products, and how are they modeled in existing product models?
2. What are CM functions, and how do the existing systems support these functions?

3. How do CM functions use product information?
4. What should CM-oriented product models look like?

The above questions have led to a research methodology illustrated in figure 1. The methodology involves three major steps. As a first step, to conceptually map types of product information, a very high-level classification of the information is investigated. Existing product models are reviewed for these information ingredients from a CM perspective, with an eye towards improving the support for CM functions in these models.

The second step involves the classification of CM functions and systems. A framework has been developed for top-down classification of the functions. The resulting classification would help in identifying potential CM information systems. A review of the existing commercial CM systems has helped verify the results of the framework and identify the missing areas for systems modeling and development.

The answer to the third and fourth questions above will be sought in the third phase of the research, by exploring a specific CM application area, and examining the exact role of product model data relative to that application. The output from the second phase will lead to the selection of a CM function and development of product models for that function.

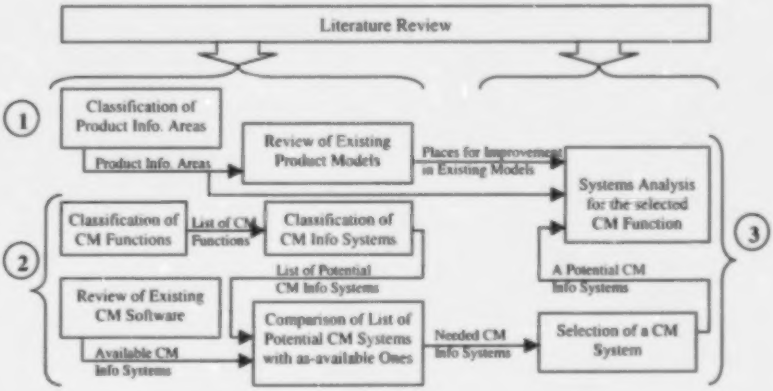
Literature Review
①
Classification of Product Info. Areas
Product Info. Areas
Review of Existing Product Models
Places for Improvement in Existing Models
Systems Analysis for the selected CM Function
②
Classification of CM Functions
List of CM Functions
Classification of CM Info Systems
List of Potential CM Info Systems
A Potential CM Info Systems
③
Review of Existing CM Software
Available CM Info Systems
Comparison of List of Potential CM Systems with as-available Ones
Needed CM Info Systems
Selection of a CM System

Fig. 1: The research methodology

The methodology of the research demonstrates a coupling of both top-down and bottom-up approaches, complementing each other. Development of our conceptual frameworks and analyses are top-down while review of the literature and the existing CM software systems and product models are bottom-up.

4 Product data and construction management

Defining basic inter-related product concepts, this section discusses on how product data may be viewed and used by CM functions.

4.1 Product, space, and material

A product can be conceptually classified according to the nature of its constituent elements and the type of product data that is used in the product development processes. A product (e.g. a building) that becomes the subject of a construction contract is comprised of two major elements: 1) *tangible product* (i.e. what is visible and can be touched), and 2) *space* (e.g. zone, floor, room, etc.). The tangible product, in turn, encompasses two elements: 1) physical product, which we call *target product* (e.g. walls, doors, technical equipment such as a heat generator, etc.), and 2) *material* from which that target product is developed (e.g. concrete, brick, pipe, insulation, etc.). We refer to material as is needed and used by CM functions (e.g. materials management and quality control); i.e. the physical material.

4.2 Product and its data in different views

The data that describes the form or shape of a product is perhaps some of the most important references regularly used by processes of CM functions. Shape-related product information is comprised of topological and geometrical information. *Topology* refers to the physical structure (or configuration) of components, while *geometry* encompasses dimensionality of components. Inclusion and intersection are two examples of topological concepts. Size, height, and length, on the other hand, are geometrical concepts.

The product's form data is used by the processes of PM functions and becomes an integral part of the input data used to evaluate and analyze process elements. A typical example is the use of size (e.g. length, width, and height), numbers, and location (e.g. zone, block, floor, etc.) of product items for estimating purpose. Not only do such data help in the preparation of product bills of quantities, but they are also used for CM engineering purposes. The shape and size of a concrete foundation or wall specified in drawings, for instance, are used for formwork design. This means that there is a relationship between shape characteristics of (tangible) products and that of the resource used for their construction.

Progress reports prepared during construction are another example of a CM function that references the geometrical information of products. The *square meter of walls* completed in a particular day, the *length of road* paved in a day, and the *cubic meter of concrete* (i.e. material) placed in *foundation walls* are some instances in which geometrical data about product plays an important role in the definition of the concepts used in CM processes. A major use of this as-built data about products is further made for productivity analyses and control as well as cost control purposes.

Selection of a construction method for a particular job is heavily dependent on the size of the job. Resource selection is a process that usually requires the (target) product's shape data. Compatibility of size of equipment with size of the product is a major criterion in this selection (e.g. considering shape and size of a building for selecting and locating cranes and scaffoldings).

Spatial information is an essential and integral part of product models of AEC projects, especially building projects. Arranging spaces is at the heart of the architectural design process (i.e. translating required functions into spaces, containing physical components; e.g. a set of rooms containing shared walls, columns, windows, door, etc.).

However, spatial and physical component information may play different roles in different project views. Each functional view of design (e.g. architecture, HVAC, structure, etc.) and construction (e.g. procurement, scheduling, etc.) may look at space differently. The perception that a project participant may have of a space and the information in which they are interested is dependent on the type of manipulation that that may perform on the space and its data. For instance, to the construction manager, space is a something of which he can temporarily use during construction (e.g. for storing materials, housing construction office personnel and laborers, etc.). This view of space is in contrast to that drawn by an architect: a fully furnished and decorated room, for example, with no sign of construction activity.

Nonetheless, not all data generated during design may be used as input to CM systems. For example, a construction manager may not need to know about the required energy, solar heat gain, internal heat gain, etc. which are used for energy analysis of spaces during design. Quality management (QM) might rather be interested to know the final specification of the product, such as heat power of the technical system required to be installed (i.e. what gives the total required heat for a space). The result of such analyses is transferred to CM functions in the form of as-required performance data. QM functions are a major user of performance data.

4.3 Material information

How does a project manager look at construction material and its information? Material is defined as: "substance or things from which something else is or can be made" [Oxford Dictionary 1989]. In construction, material may be used not only for constructing a target "product" (e.g. constructing a column from bulk concrete) but also for assembling a "resource" (e.g. making a ladder or concrete formwork from pieces of woods received on the site). This is the view of the construction and facility manager. However, in the existing models, material is not usually modeled as "physical material", but as "material properties", which may be enough for engineering analysis and design but not for construction. This appears as a bottleneck in transferring material information electronically from design to construction. The same problem would exist during operation and facility management.

The quality control function, for example, looks for information describing the quality—both as required and as-constructed—of items, such as the finish of a column, slump of the concrete received on the site, or strength of a concrete test sample block. Some of this information may have been provided during the design, however, other information may not be provided, or at most, may be fragmentally scattered throughout the design documents and specifications in text form with no linkage between them.

The material management function is another example which needs some form-and-performance-related information about materials and some association between this and the physical product for materials space handling. Materials information together with shape characteristics of space is a basic input to both the processes of space management for activity scheduling and material handling. Avoiding congestion and interference in construction processes is highly dependent on the size of space available to the crew [Riley and Sanvido 1995].

Consideration of *space*, *target product*, and *material* as three closely interrelated product elements in a product model would enhance the integrity and effectiveness of the models. Topological and geometrical characteristics then must be modeled as they relate to any form of product (i.e. space, target product, and material).

5 Classification of construction management functions: A framework

The literature on general project management and construction management elaborate the processes involved in the management of construction projects. Some of the literature has attempted to classifying the functions and processes involved. Based on a literature review, we have developed a framework that helps provide a comprehensive list of CM functions. Such listing can be used for classifying and developing CM information systems.

5.1 The PMBOK

In "the Project Management Body of Knowledge" (PMBOK), the Project Management Institute (PMI) divides project processes into two groups: "PM processes" (i.e. those concerned with describing and organizing the work of the project); and "product-oriented processes" (i.e. those concerned with specifying and creating the project product) [PMI 1996]. Concentrating on PM processes, the PMBOK groups the processes into nine knowledge areas.

The PMBOK describes project management in general. It covers the major areas and processes of project management common to all types of projects. However, some processes common in construction management are not covered, such as equipment management, materials management, and safety management. Materials handling and distribution plays a significant role in the progress of many types of projects (including construction) as does materials procurement, which is considered in the PMBOK in the form of acquiring goods and services. Overall, the PMBOK provides a good reference for identifying PM functions, but modifications and extensions are needed in order to cover a full range of construction management functionality.

5.2 Dimensions of project management

Three basic dimensions can be defined for construction management: project objectives, project elements, and basic CM functions. We use these dimensions to devise a framework to classify CM functions.

5.2.1 Project objectives

The goals of every construction project are to be completed with the right scope, within a reasonable time, cost, and quality, without injury and accident, and at minimal risk. Thus, at the very highest level of importance, the objectives of management of a project are summarized into control of *scope, time, cost, quality, safety,* and *Risk*. These objectives govern all the processes involved in the development of the project. We have considered PM objectives as one of the basic dimensions of our PM framework.

5.2.2 Project elements

Construction management involves the use of resources to create a targeted product in an environment. We call these resources, product, and environment *"project elements,"* specifically: *human resources*, *equipment and tools*, *materials*, *money/financial* resources, *information*, target *product*, and project *context and externals* (e.g. vendors, customers, competitors, environment, etc.). The progress of a project is dependent on these elements.

5.2.3 Basic construction management functions

Regardless of types or phases of projects, there are a number of basic functions which are performed in managing a project. Kavanagh et. al [1978], list five basic functions from which scientific management is comprised: *planning*, *control*, *organization*, *coordination*, and *direction*. PMI, in another approach, groups PM processes into five "process groups": *Initiating*, *planning*, *executing*, *controlling*, and *closing* [PMI 1996].

There are major overlaps and similarities among these proposed classifications. We draw from these to classify basic PM functions into seven groups:

1. *Initiating*: recognition of a need for a project and commitment to carry it out,
2. *Planning*: developing and maintaining project plans,
3. *Organizing*: selecting and arranging project resources,
4. *Executing*: implementing the project plan,
5. *Controlling*: tracking of execution of project plans to ensure project objectives,
6. *Closing-out*: formalizing acceptance of the product and closing the project, and
7. *Following-up and Redirecting*: providing warranty services and learning from project processes.

The basic CM functions are those generic and conceptual activities that are usually performed in the progress of a typical project. These functions are generic in the sense that they may be exerted at any specific phase (e.g. design, construction, operation and maintenance) or the total life cycle of a construction project (i.e. from inception to operation and demolition of the facility).

5.3 The framework

Figure 2 illustrates a three dimensional rectilinear grid representing the three major conceptual PM dimensions on its three axes. Each grid cell in a coordinate plane would identify a function, holding a number of processes, relating to the two corresponding dimensions concepts (e.g. cost control for cost and controlling extending vertically throughout project elements).

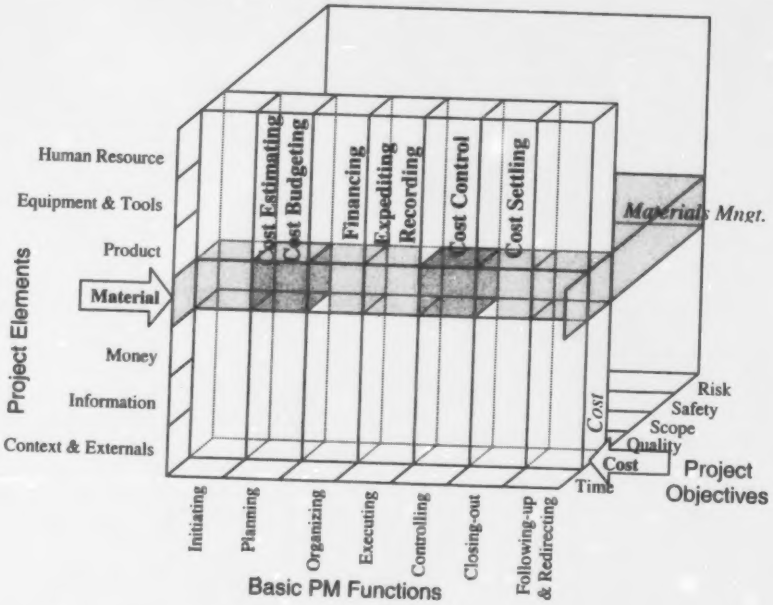

Fig. 2: Dimensions and functions of project management

Each three-dimensional grid coordinate (i.e. cube) would represent a conceptual process, holding a number of sub-processes, originating from the three corresponding dimensions concepts (e.g. materials cost control at intersection of material, cost, and controlling). The figure illustrates how the three dimensional rectilinear grid can be used to identify processes, here relating to how materials management may interact with cost management. This framework is flexible, and the coordinates would help us identify any possible functions of CM from different perspectives (e.g. project *planning*, *cost* management, and *materials* management).

6 Conclusions

This paper presented some of the dimensions and visions of an on-going research project aimed at product modeling for construction management. This includes the objectives and overall methodology of the research, and some of the visions and conceptualization stages of the research.

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265 HIGHLIGHTS OF THE DEVELOPMENT PROCESS OF INDUSTRY FOUNDATION CLASSES

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Abstract

The Industry Foundation Classes, IFC, are developed by the International Alliance for Interoperability, IAI, to provide for data exchange and sharing capabilities for the building and construction sector of the industry. Since the foundation of the IAI in 1995 two releases of IFC have been published and the third release is on its way. Many prototype implementations by leading software companies have proved the IFC specifications, and commercial products to satisfy the end user demands can be expected within the next few quarters. The paper highlights the major development steps between the recognition of end user needs to improve business processes and the fulfillment of those needs by IFC specifications and implementations. Emphasis is put on the modeling of business processes, the provision of use cases, the integration of domain requirements within a single integrated but modular information model, and the underlying methodology and model architecture.

Keywords: Information model, Data exchange and sharing, Software Interoperability

1 Introduction

Since the IAI was established internationally in 1995 two major IFC Releases have been published:

- IFC Release 1.0 in January 1997 (IAI 97a)
- IFC Release 1.5 in November 1997 (IAI 97b), including the technical corrigenda published as IFC Release 1.5.1 in August 1998 (IAI 98)

During the 3 year period major technical goals have been achieved but some adjustments have also been made to the development methodology and

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architecture. This occurred concurrently with the continuous growth and international coverage of the IAI, which now has around 600 member companies within 8 international chapters covering over 20 countries.

The technical answer to the challenge of collaborative development between various contributors internationally and within several domains was the subject of two major documents in addition to the IFC model specification:

- IFC Specification Development Guide (IAI 97c)
- IFC Object Model Architecture (IAI 97d)

The authors participating in the development of all documents mentioned above want to highlight the major development tasks as defined within the Guide and to present the ideas behind establishing a well defined and rigid model architecture to maintain a single integrated but modular IFC object model.

By the time this paper is presented, the current version of IFC will be implemented as pre- and postprocessors in commercial software by leading software companies, such as by Autodesk for the Architectural Desktop, by Graphisoft for ArchiCAD and by Nemetschek for Allplan, to name a few. These companies are using experience gained by prototype implementations over the last 1 ½ years, in which over 40 companies from all over the world have been involved.

The next major deployment step will be demonstration projects where IFC based technology is successfully used within real construction projects. Ideas and first initiatives are described in (Wix & Liebich 98).

1.1 Related work

The relatively fast development of IFC from its initial concept in 1996 to commercially implemented release in 1999 would not have been possible without the experience and information sources coming from other previous or ongoing projects and initiatives.

Starting from the GARM, General AEC Reference Model (Gielingh, 88), various attempts have been made to use Product Modelling techniques to capture the semantics within the construction objects. Within the European ESPRIT projects, the projects ATLAS, COMBINE, COMBI and now VEGA, TOCEE and CONCUR explored the applicability of Product Modelling within demonstration scenarios coming from the construction industry. Other major input came from the ISO standardisation efforts in STEP, "Product data representation and exchange". In particular the EXPRESS language (ISO10303-11 94) and the STEP physical file format (ISO10303-21 94) are used as the fundamental technologies in IFC. Moreover, parts of the Integrated Generic Resources have been adopted to form part of IFC resources in order to reuse proven concepts coming from other industry areas. The development of Part106 also influenced the IFC and vice versa (ISO10303-106 97).

Acknowledging already existing standards within the same industry area, most notable AP225 (ISO 10303-225 97) and CIMsteel (CIMsteel 94), the concept of an Interoperability Adapter has been incorporated into the IFC structure from the beginning to establish the scenario of schema mapping to external Product Models. This has been strongly facilitated by the execution of a liaison agreement and memorandum of understanding with ISO TC184/SC4 (ISO

TC184/SC4 98).

1.2 New technologies

Although the current IFC Release is developed and implemented mainly using the data definition language EXPRESS and file based exchange, the aims of IFC specification are more far reaching, including (see figure 1):

partial data exchange,
model server based implementation,
software interface based implementation.

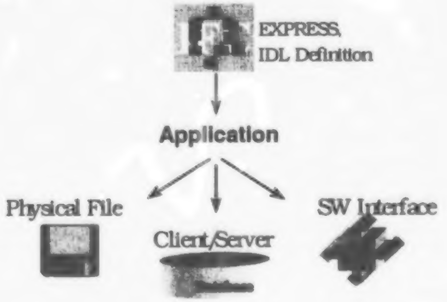


Fig. 1: Implementation scenarios for IFC

In order to support these implementation scenarios the IFC model development:

follows modular architecture approach,
restricts EXPRESS language features that would impede alternative implementation,
adds additional specifications into the IFC model documentation.

The EXPRESS specification of IFC is complemented by a prototype IDL specification, according to the Interface Definition Language, as published by the OMG (OMG 95) and ISO 10303 part 26 (ISO10303-26 98).

2 IFC development cycle

The cycle of one IFC release comprises the following mayor steps:

1. Define user requirements
2. Define business process within a project
3. Test by usage scenarios
4. Specify domain models
5. Integrate into current release of IFC
6. Review new release of IFC
7. Finalise documentation

8. Define conformance
9. Support implementation

The accomplishment of all tasks requires the active participation of many contributors. The IFC Specification Development Guide (IAI 97c) provides the modus operandi for the collaboration.

2.1 Roles within the development cycle

IFC specifications are developed by groups of experts. Each expert group performs various development steps and reviews others. The principal groups that can be identified are:

- project groups for defining the requirements;
- technical experts for specification and integration;
- software vendors for implementation.

The roles and responsibilities of the groups are presented based on the following premises:

- the knowledge required for collaboration (overlapping fields of knowledge);
- the responsibilities for the various development processes;
- the review tasks and the documentation requirements within the development processes.

2.1.1 Domain experts

A project develops industry requirements for interoperability within its area of interest. The requirements are then presented in a form that enables a formal information model to be developed.

Participants within a project include domain experts who must have technical expertise in its area of interest. It is useful if members also have knowledge of the capabilities of application software currently used within that domain. Projects are responsible for development tasks 1 to 3, as outlined in section 2. Major work to be undertaken by domain experts within a project is:

- project initiation and scope definition;
- technical analysis and usage scenario;
- specification review.

2.1.2 Technical committees

The International Technical Management Committee (ITM) is the principal technical body within the IAI. All other technical committees report to the ITM. Its responsibilities are to:

- provide the technical planning and management required for IFC development;
- co-ordinate international technical work;
- monitor the IFC specification process.

ITM is responsible for the acceptance of AEC project proposals (result of development tasks 1 to 3) and for the acceptance of the final IFC Release (result of tasks 4 to 7).

The Specification Task Force (STF) provides high level technical support to IFC specification developers and implementers, to guide the object model specification work and to produce the necessary technical documentation. Within the STF, technical experts perform product definition work and are responsible for IFC model synthesis. The definition and maintenance of the IFC model architecture belongs to their tasks as well. STF is responsible for development tasks 4,5,7 and provides heavy input into 8 & 9. The following tasks are the responsibility of the STF:

- develop the technical architecture;
- define or supervise the specification of domain models coming from AEC project proposals;
- integrate IFC definitions;
- maintain previous IFC releases;
- continuously enhance the fundamentais of the IFC specifications;
- develop the IFC Release document suite;
- support software implementers.

2.1.3 Software implementers

The Software Implementation Committee allows software implementers to work together in a spirit of open, pre-competitive collaboration to ensure that the IFC Object Model can be implemented in practice. Software implementers are responsible for:

- pilot implementation of selected IFC data or interface definitions;
- realisation of commercial implementation according to the companies' business plans;
- feedback into the specification work;
- review of IFC data or interface definitions and project definitions.

Software implementers have a particular responsibility to the IAI in providing both the pilot and commercial implementations of IFC. It is only through such implementations and the demonstration of their capability that IFC will be deployed throughout industry and that support of the IAI by industry will grow.

2.2 Development tasks

This section presents an overview of all tasks necessary to develop solutions for current gaps in information sharing as indicated by professionals. An example coming from engineering maintenance is used throughout the section.

All developments should start with the recognition of potential business benefits by professionals in industry. To illustrate the potential improvements expected from proper information handling in engineering maintenance the following assessment had been made by a senior bank representative: 25% of the total facilities maintenance budget deals with engineering maintenance, if 10% of that could be saved, the total savings would be in a range of $15m to $30m for the properties owned by a major bank (Goodman 97, see also Wix & Liebich 98).

2.2.1 Definition of user requirements

This first stage is about deciding the project on which work is to be carried out. The objective is to select one or more industry processes that can be broken down into manageable and useful parts. Each part should be able to be completed within the time scale of the target IFC release.

Once the industry processes has been selected each task within the process needs to be described. The description follows the wording as normally used by professionals and is complemented by figures (example given in Fig. 2 and Table 1).

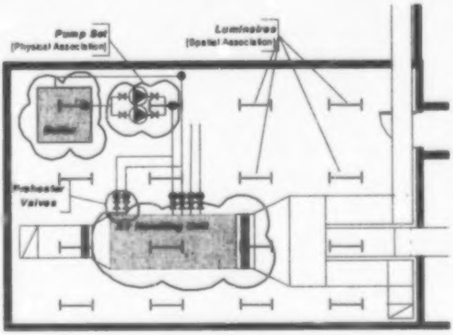


Fig. 2: Task: Group objects as assets, shown as figure

Table 1: Task: Group objects as assets, shown as text box

Example task description

Group objects as assets

- This task involves the specification of the asset. An asset can be either a single object or may be a group of objects upon which a single maintenance action is to be specified.
- A large item of equipment such as an air handling unit, boiler or transformer will probably be uniquely identified as an asset.
- An asset may be declared as a group of objects with a spatial identity such as the light fittings within a room.
- An asset may be declared as a group of objects with a system identity such as the steam traps within a system (or subsystem).

2.2.2 Definition of domain processes

A process model is a formal description of the tasks undertaken to complete a defined industry process and sets them into a sequence. For the next stages it provides the basis for identification of the object model scope.

Process models are fairly easy to understand. Domain experts, with some guidance from modeling specialists, can create and understand process models with little training. A process model contains:

- tasks performed during the process execution;
- decomposition of processes in a hierarchy;
- sub-processes that are usually nested within processes;
- relations between processes, forming a sequence;
- main relations are input, output and control;
- mechanisms may also be defined which provide the means of executing individual tasks.

The process modeling method used for IFC development is an adapted form of TQM modeling, an example is given in Fig. 3. The use of IDEF0, the most recognized process modeling language, is proposed for the future (IDEF0 93).

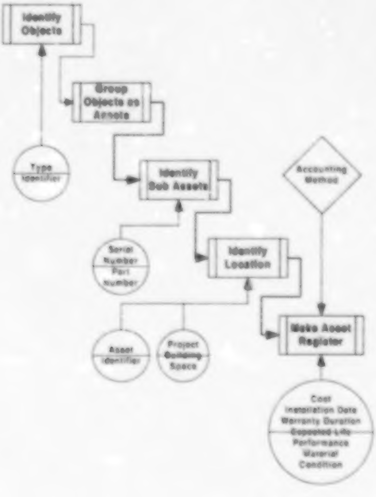


Fig. 3: Process model for sub process: Asset register

The usage scenario is a textual description that sets down the complete information requirement in such a manner that it relates together the scope definition, the process model and the object specification. At this stage, the specification does not exist. The usage scenario identifies its elements (see Fig. 4 for graphical description and Table 2 for lexical description).

When creating the usage scenario, the following rules shall be observed:

1. *Be assertive*: a usage scenario should provide a set of assertions that can be modelled and implemented: An asset is located within a space;
2. *Be clear:* about the ideas being captured by the usage requirement. In the above, asset and space are clearly identifiable as classes;
3. *Be specific:* about relationships. In the above, the relationship 'is located on' is captured;
4. *Be precise:* concerning numerical constraints which exist. Frequently, this

can be directly understood from the statement in the usage scenario. The 'is located on' reads inverse as a space locates 'zero-to-many' assets.

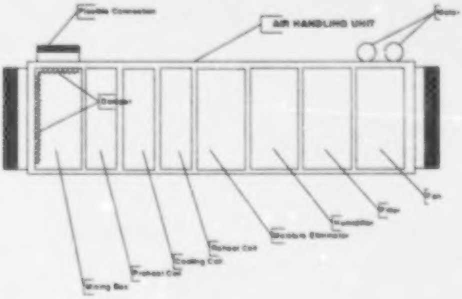


Fig. 4: Air handling unit as usage scenario

Table 2: Example usage scenario

Identify sub assets

The decomposition of the asset into component parts or sub assets may be already known by virtue of the separate existence of the elements making up the asset (as in the case of the pump set and the luminaries). Alternatively, it may be necessary to identify the parts of the asset requiring individual maintenance actions where the element forming the asset is bought in as a single item. This will be the case for the air handling unit and the boiler.

Separate components of an air handling unit include:
- Fan (motor[s], impeller, drive wheels and belts)
- Filter
- Pre-heater coil
- Re-heater coil
- Cooling coil
- Dampers (fresh air and re-circulation)
- Moisture eliminator
- Humidifier

Separate components of a boiler include:
- Burner assembly
- Controls
- Heat exchanger

Drawings and sketches improve the quality and completeness of a usage scenario. They also help modelers and software implementers to understand how to realize the classes and relationships as expressed. An early indication of the data operated on in each usage scenario is required as well (see Fig. 5).

2.2.3 Specification of domain model

The domain model specification is carried out in two steps:

1. Set of assertions about statements in task descriptions, process models and usage scenarios
2. Formal data model for all classes and relationships handled by the processes in scope.

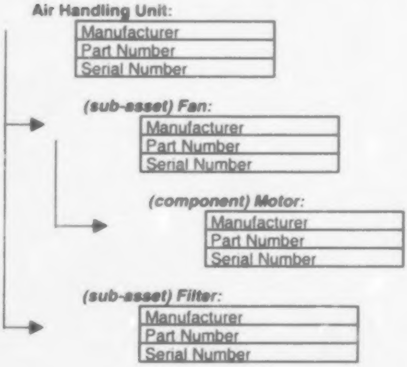


Fig. 5: (Partial) decomposition of air handling unit

A set of assertions breaks down the usage scenario into simple sentences. Each assertion is the simplest sentence that can be developed. Optimally it contains two nouns and a verb, plus some qualifying grammar that is used to describe cardinality and rules (see Table 3). The objective of developing assertions is to:

- identify classes;
- identify relationships;
- identify cardinality of relationships;
- identify direction of relationships;
- identify attributes;
- identify rules (uniqueness, derived values, constraints).

Table 3: Example assertions

Identify sub assets

- An **air handling unit** *consists of* one or many **fans, filters, coils, dampers, eliminators,** and **humidifiers**
- A **fan** *consists of* one or many **motors, impellers, drive wheels and belts**
- A **fan** *is characterised by* ***Manufacturer name, Part number and Serial number***

Class | *Relationship* | Cardinality | ***Attribute***

During the formal definition of the domain model the assertions are transformed into statements using an acknowledged modeling language, here EXPRESS, and the graphical notation EXPRESS-G (see Fig. 6).

The formal definition also marks the point where the transition from the responsibility of the domain team to the technical team occurs. The basic indications shall be given by the domain team suggesting which information requirement can be best realized from the user perspective as class, attribute, property set, and which are the appropriate relationships, including inheritance, aggregation, or has relation (see figure 7). Further refinement is than needed from technical and modeling experts to guarantee that the final domain model also meets the requirements of conceptual clarity and model consistency and that it follows a common modeling philosophy. All of the above ease the later task of model integration.

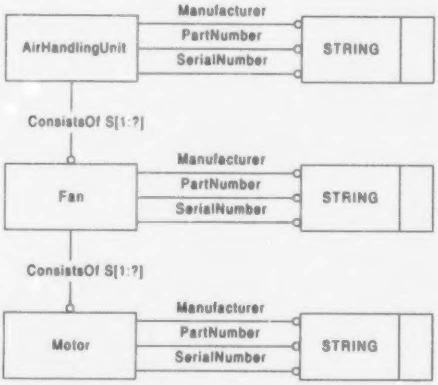


Fig. 6: EXPRESS definition example from domain model reference to this

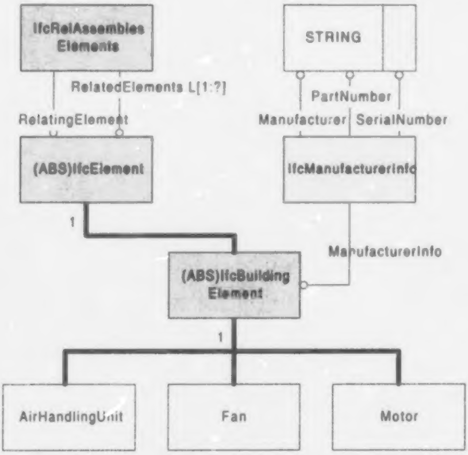
2.2.4 Integration into current release of IFC

When the domain specifications are completed, they undergo synthesis. This ensures that common ideas are managed consistently and can be implemented equivalently by different software applications. The result of synthesis is a new release of the integrated information model, IFC. Good domain specifications have already been developed by taking into account the need for synthesis by:

- using facilities provided by the existing IFC resource models;
- referencing the basic concepts already provided by the IFC core model;
- cross checking with other either already existing or newly proposed domain models for overlap.

During the integration process the modeling experts, namely the STF, carry out processes of synthesis that will take account of: (see Fig. 7)

- ideas already included in the IFC Object Model;
- ideas which are common between domains;
- ideas which are similar between domains (trying to make them into common ideas);
- truly new ideas.



Grey box : Idea already included in IFC
Grey stripes: Ideas common between domains
White box: New ideas

Fig. 7: EXPRESS definition after synthesis

The synthesis results in careful additions to the current IFC release which reflect the domain needs not already handled by existing model components. The main risk of a growing (and thereby changing) information model is, however, that previously supported definitions could inadvertently be affected by changes due to the highly interconnected nature of considerably sized information models. Two principle solutions are discussed to solve that problem:

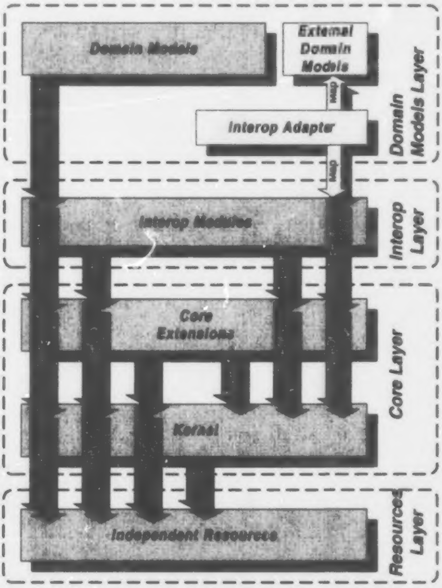
1. Prohibit any changes to the existing generic information model.
2. Provide a modular architecture for the information model to maintain changes as needed.

The STEP standardisation follows the first solution. New requirements coming from domain models (called Application Reference Model, ARM) have to be mapped down to the Integrated Generic Resources. The mapping is described in mapping tables that form part of the standard. Definitions given in the Integrated Generic Resources can only be further constrained, i.e. by providing constraints in subtypes or rules, however they can not be enhanced. The result is an Application Integrated Model, AIM. The disadvantage is, that the semantics of the domain model get confused by mapping concise domain constructs into various very generic resource definitions.

The IFC approach is different and follows the second solution. The IFC model is decomposed into many modules defined at various layers of abstraction. Strict referencing rules apply to necessary links between the modules at each layer. The architecture operates on a 'ladder principle', also known as the software engineering layering principle:

- Any class may reference a class at the same or lower layer but may not reference a class from a higher layer.
- References within same layer must be designed very carefully and are only allowed within the Core layer and the Resource layer.

Fig. 8 shows the strict downward reference within the IFC Architecture. It is described in further detail within the IFC Architecture document (IAI 97d). The IFC Release 2.0 being under development relies on the same architectural structure, but added more content to each layer.



Red arrows: Reference for uni-directional association
Blue arrows: Reference for inheritance relationship
Yellow arrows: Mapping between IFC and external models

Fig. 8: IFC Architecture reference to this?

Whereas the resource and core layers remain quite stable the incremental growth will occur within the interoperability and domain layers. Release 2.0 particularly enhance the IfcSharedBldgElements and IfcSharedBldgServiceElements for building elements shared by many domains or application types and adds the IfcSharedSpatialElements for shared space related information. The IfcArchitectureDomain, IfcHvacDomain and IfcFacilitiesMgmtDomain increases for building elements dominantly used by a single domain or application type and further domain schemas are added to deal with cost estimating and construction management.

The STF works on three versions for each release reflecting different states of the synthesis:

- *Alpha version* represents the consolidated domain models where all ideas already included in the IFC model are filtered out and the new requirements are highlighted as deltas. The alpha models are pre-integrated.
- *Beta version* represents the integrated IFC model, where the deltas from the alpha version had been added and the ideas which are found common or similar between domain models had been generalized. The beta model is the next IFC release for review and comments.
- *Final version* is the next official IFC release for implementation after all issues coming from the reviews had either been incorporated, postponed (for inclusion into further releases), or rejected

2.2.5 Review of new release of IFC

It is important that IFC developments are reviewed by industry experts, information modelers and software engineers for the following reasons:

Table 4: Review types and participants

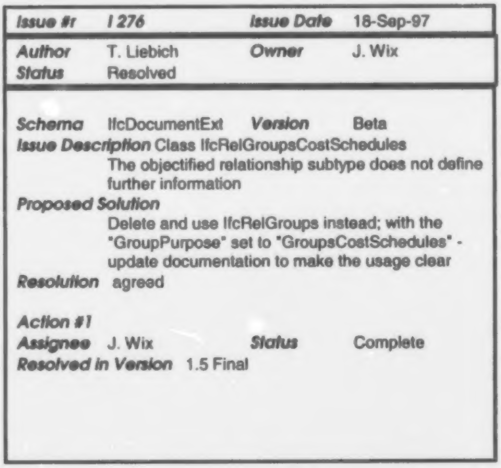
You are ...	**You should review**	**To determine ...**
A manager (either within AEC/FM or IT applications)	The domain specification scope statement and usage scenario	Whether this domain specification meets your business needs
An industry expert, or a modeller responsible for developing specifications and systems that support business processes	All of the above, plus The information requirements and their supporting material	Whether all the data that you use for the business process is completely and correctly identified
An applications software developer, or a modeller involved in designing and developing systems	The domain specification and its supporting material	How the domain specification can be mapped to your application's data, or to the data held in your database(s)
An applications software developer	The exchange sets	Which exchange sets are aligned with the scope of your application

- ensures that the specification is validated by the agreement of a number of industry experts;
- identifies aspects of the domain process which have not been fully included;
- ensures that the specification is internationally applicable;
- provides a wider range of expertise for the specification development and allows for the correction of inaccuracies within the specification.

Table 4 identifies typical reviewers, what they should review and their purpose in doing so. Any specialist in any of the above mentioned professions is invited to review the IFC in total or in parts.

All issues raised against an IFC model are captured within the IFC Issue Resolution Database, IRD. The STF receives all issues and decides about the status, accepted or rejected, and if accepted, whether it can be resolved within the current release or whether it has to be postponed for the next release. For each accepted issue the proposed resolution, if given, is considered and actions are assigned to the responsible information modellers within the team to finally adjust the IFC model. Table 5 shows the record of an issue.

Table 5: Printout from the issue resolution database



Issue #r ***I 276*** ***Issue Date*** 18-Sep-97

Author T. Liebich ***Owner*** J. Wix
Status Resolved

Schema IfcDocumentExt ***Version*** Beta
Issue Description Class IfcRelGroupsCostSchedules
The objectified relationship subtype does not define further information
Proposed Solution
Delete and use IfcRelGroups instead; with the "GroupPurpose" set to "GroupsCostSchedules" - update documentation to make the usage clear
Resolution agreed

Action #1
Assignee J. Wix ***Status*** Complete
Resolved in Version 1.5 Final

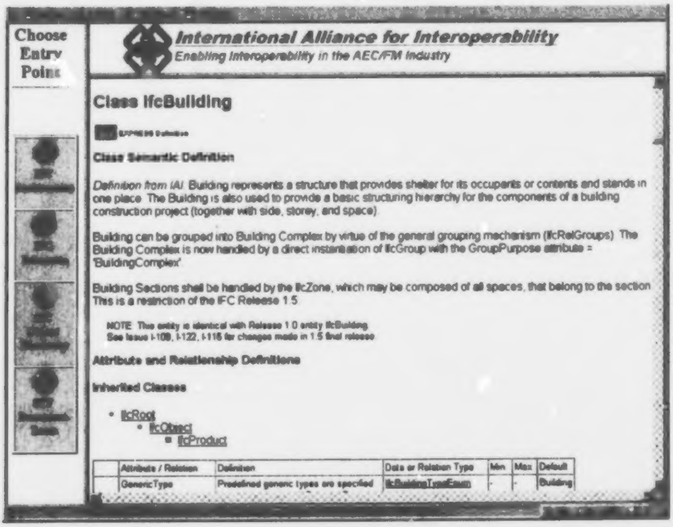
2.2.6 Final documentation

The final version of an IFC Release is published by a series of documents:

- Introduction to IAI and the IFCs
- IFC Object Model Architecture Guide
- IFC Specifications Development Guide
- IFC Object Model Specification
- Vol. 1 – AEC Processes supported by IFC
- Vol. 2 – IFC Object Model Guide
- Vol. 3 – IFC Object Model Reference
- Vol. 4 – IFC SW Certification Guide

Whereas the IFC Object Model Specification is only available to the IAI membership, the other documents are in the public domain. To ease the access to the model specification, the Introduction to IAI and the IFCs and the IFC Object Model Reference are also provided as HTML documents. The IFC Object Model Reference is fully hot linked so that all parts (the specification text, the EXPRESS definition, the IDL definition, and the Property Set definitions) are inter linked (see figure 10).

The other two steps, as mentioned in section 2, Conformance class definition and Implementation support, are not discussed within this paper. Both are of particular interest to the IAI software developer community.


Choose
Entry
Point
International Alliance for Interoperability
Enabling Interoperability in the AEC/FM Industry
EXPRESS Definition

Class IfcBuilding

Class Semantic Definition

Definition from IAI Building represents a structure that provides shelter for its occupants or contents and stands in one place The Building is also used to provide a basic structuring hierarchy for the components of a building construction project (together with side, storey, and space)

Building can be grouped into Building Complex by virtue of the general grouping mechanism (IfcRelGroups) The Building Complex is now handled by a direct instantiation of IfcGroup with the GroupPurpose attribute = 'BuildingComplex'

Building Sections shall be handled by the IfcZone, which may be composed of all spaces, that belong to the section This is a restriction of the IFC Release 1.5

NOTE This entity is identical with Release 1.0 entity IfcBuilding
See Issue I-109, I-122, I-116 for changes made in 1.5 final release

Attribute and Relationship Definitions

Inherited Classes

- IfcRoot
  - IfcObject
    - IfcProduct

	Attribute / Relation	Definition	Data or Relation Type	Min	Max	Default
	GenericType	Predefined generic types are specified	IfcBuildingTypeEnum	-	-	Building

Fig. 9: Snapshot of the HTML documentation of Volume 3

3 Conclusion

None of the individual steps as outlined above are new; they all had already been described in various papers and had been used in several projects.

What is remarkable, however, is that within the IFC development process they had been merged to a methodology applicable for industry-wide and commercial use. Even as this paper is presented, leading software companies are implementing and deploying IFCs within their commercial products. The companies involved have a market share of 2/3 of the European market for architectural software.

4 Addendum

This paper refers to the development of IFC Release 1.5.1. Presentation to the CIB W78 meeting will include example material taken from IFC Release 2.0 which is scheduled for public issue in April 1999. Release 2.0 provides specifications that meet the business process requirements of the processes as shown in Table 6. The following picture shows the intermediate stage of the IFC Release 2.0 architecture that reflects the growth in comparison with IFC Release 1.5 (see also Fig. 8.).

Table 6: Domain projects for IFC release 2.0

Architecture AR-1 Enhancement of the Architectural Model AR-2 Space planning for escape routes	Facilities Management FM-3 Property Management FM-4 Occupancy Planning
Building Service BS-1 HVAC Systems design BS-3 Pathway co-ordination with other trades BS-4 Thermal loads calculation	Codes and Standards CS-1 Code compliance checking CS-2 Code extensions
Simulation SI-1 Photometrically Accurate Visualisation	Estimating and Scheduling ES-1 Cost Estimating
Cross Domain XM-3 Network Model and Model Constraints	

5 Acknowledgement

The authors want to acknowledge the consensus driven team effort within the Specification Task Force that enabled the realisation of IFC. The IFC Release 1.5.1 was developed by James Forester, Richard Junge, Jean-Luc Monceyron, Richard See, Kevin Yu, and the authors. For IFC Release 2.0, the team has been strengthened with the addition of Juha Hyvarinen, Kari Karstila, Robin Drogemuller and Jiri Hietanen

The examples have been taken from the IFC Release 3.0 domain project FM-1 Engineering Maintenance developed under the leadership of Mike Goodman with technical support by Jeffrey Wix.

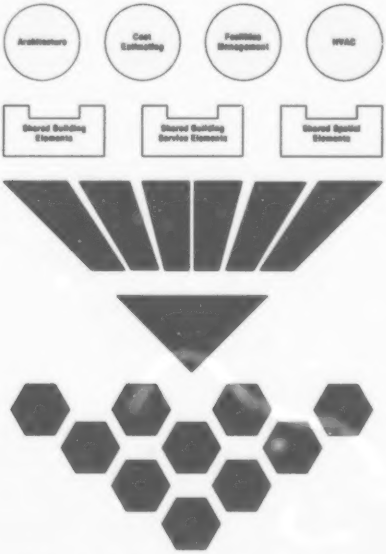


Fig. 10: IFC Release 2.0 Architecture

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266 CONSTRAINTS OF PRODUCT MODELLING APPROACH IN BUILDING

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Abstract

The ultimate goal of building product modelling has been to define the data structures that could be used to describe our entire built environment. In spite of the huge size and complexity of this task, the theoretical foundations of modelling received little attention. In the paper the traditional foundations of the modelling approaches are questioned. An unorthodox perspective on the computerised representation of the real world is introduced. The view is based on Heidegger's philosophy and Winograd's critique of artificial intelligence. The author exposes the difference between the modelling of material phenomena (such as in structural mechanics) and the modelling of knowledge and information. He makes a distinction between physical models and anthropo-technical models. He claims that the latter are not objective but subjective. This is the major constraint in using product model technology in building. The author concludes that building product and process models do not model objective reality but the modeller's subjective understanding of that reality Therefore several correct but different models may exist. Based on the analysis the following information technologies look promising: simple generic models that allow room for different (even wrong) interpretations; generic software that allows uses outside the intended scope; friendly software that does not build a barrier to engineer's being in the world; non model-based software to support creative design; communication software to support commitment negotiation instead of information exchange. Complete product models and product models for creative design are not possible.

Keywords: Product models, modelling, structure, computers, expert systems, creative design

Durability of Building Materials and Components 8 (Volume Four). *Edited by M.A. Lacasse and D.J. Vanier.*
Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17743-9

1 Introduction

In spite of extensive research there are still surprisingly few tools available, that support creative design; few expert systems and AI tools have matured to commercial levels; computable representations of standards are almost not existent; SGML based structured documents are not used; product modelling has been around for a decade yet standards are developed slowly and commercial applications are rare. On the other hand, several information technologies have received almost no attention from researchers, but are widely used in practice - for example mobile phone and fax technology, computer aided communication/co-ordination software, rather simple 2D drafting software, spreadsheets, word processing software and file based, black-box document management systems etc.

1.1 A better understanding of how humans operate is required

In this paper the author presents a philosophical background that explains this difference. It explains some of the problems that the researchers and developers in several fields of construction IT are facing. It does not solve them but suggests they could be unsolvable and that, as engineers, we should try avoiding, rather than solving them. The philosophical background that will be used is radically different to the tradition in which scientists are brought up and may, at first glance, appear unscientific: it claims that the human mind does not primarily operate rationally on mind models of the real world. Engineering software relies heavily on the models, but after reaching a certain level of bureaucratic intelligence and efficiency, the models could become an obstacle. The philosophy presented may or may not be correct, but it contributes to deeper understanding of how humans work and think, and what computers can do to help them.

1.2 Paper structure

In section "Modelling" the author defines the context of the paper - product and process modelling. In section "Tradition" the traditional approach and philosophical background of modelling are presented. Section "Hermeneutic constructivism" presents the alternative. In section "A hermeneutic perspective on product models" the author argues that product models are subjective, cause blindness, harness creativity and are of limited use. Section "Conclusions" summarises the main points and suggests what kind of product and process models could be successful.

2 Modelling

A **model** is usually defined as an abstraction or simplification of reality. A better term instead of "reality" is "original" or "universe of discourse (UoD)" because it does not imply anything real. The process during which models are created is called **modelling**. A person making a model is **modeller**. A **formal model** is a model that is formally, usually mathematically or logically defined. To act intelligently in a domain, humans do not need a model of the domain, particularly not a formal one. For example even though structural mechanics models were not existent in the Roman time, great domes have been built. Even though we still do not have a construction process model, construction processes are carried out. We can distinguish between **three kinds of models**: physical, social and anthropo-technical models.

Physical models model phenomena of the physical world - for example a cantilever, an atom etc. Models can be verified with experiments and models themselves do not change or influence the physical world: no matter what kind of theory we have on the structural mechanical properties of a beam, if we put some load on the real thing, it will deflect in the same way, regardless of our current theory. Sciences that handle this kind of phenomena are often referred to as "hard sciences".

On the other hand, **social models** are trickier. For example if a model that poor neighbourhoods have high crime rates is published, the people in the poor neighbourhood, aware of the model, might actively do something as a response to the model, that could prove the model wrong. In this case the observer and the observed influence each other, making the models much more vulnerable and the related sciences "softer".

2.1 What are building product models

Probably, because the computers in structural engineering were first used for the computations of mechanical models and because they describe physical products, we remained under the impression that when we talk about product models, these fall into the "physical" category. But at this point we must make some more distinctions.

It is generally believed that in order to be useful, computers must know about the domain in which they operate. In programs we define **digital models** of the original. Since computer programs are created to be useful for more than one original, the **schema of the model** and the model itself are separated. During systems analysis programmers try to think of every possible original the program will encounter and define a schema into which any original could fit. Instead of thinking about particular instances they think about concepts common to all instances. We can therefore distinguish between (1) **conceptual modelling** that results in a **data schema** and related code, and (2) engineering modelling, that results in data. Examples of concepts are "a tower", "a door", "a window", "quality", "satisfaction" etc.

Product and process models model products and processes such as "the Eiffel tower", "construction of the new Boston tunnel". **Conceptual building product models** define concepts about buildings and define schemata into which data about any building would fit. Data that fits the predefined building conceptual schema is called **structured data**. Building products can also be described by **unstructured data** (e.g. a GIF image). This data, since handled by a computer, fits some schema, but not a specialised building schema.

Concepts being modelled are "physical" meaning that they are defined within a "hard" physical theory. This theory, for example, defines that to calculate deflection of the beam, we must know its geometry and module of elasticity, another may require also a Poisson's number. Conceptual modelling must define a schema into which this data fits. The meaning of this data is defined within the theory.

2.2 Product models are not physical models

But **building product models** are much wider than that. They are defined as "totality of all information about a building product throughout its entire life cycle" (Bjoerk, 1989) - meaning that a union of all schemata for "hard" and "soft" theories is required. But product models are not being defined in this way - bottom up - simply because there is not a theory behind every process and behind every piece of data about a building, that we would like product-model-based software to handle. So instead of providing schemata for the data required within a self-contained, well-defined universe, we are trying to define the schemata for the concepts that are in our minds only. For example, if in process modelling we want to model a "resource" what we do is ask ourselves what we believe a resource is and what we might, during a building process, know about it. One might say that a person is-a kind of resource, one might not. There is not a hard or soft theory that would tell us who is right. Existing computer applications that the process model should support could have different notions about this issue.

2.3 Product models are anthropo-technical models

The author calls these kinds of models "**anthropo-technical**". Anthropo (and not socio-) because they are based on an individual's understanding of the UoD. Technical, because they are about the technical artefacts around us and because technology is used to handle them. These kinds of models are softest, most vulnerable and unstable. A conceptual anthropo-technical model can change one's understanding of the concepts themselves. The author calls this the **vicious circle of modelling**: "Reality" of anthropo-technical topic is a matter of convention and not of an objectively present reality: a group agrees what "really" is. For example does a "resource" include or exclude people. Models influence the mutual understanding of a topic: a model of a "resource" makes people rethink or adapt to what they consider it to be. So the model changes the universe that was observed and modelled. It should be stressed, again, that in this case the universe, has been our own understanding of the topic and not an "objective" real world.

3 Tradition

3.1 Intelligent action is based on mental representations of the real world

According to the traditional rationalistic philosophy the difference between the "reality" and our understanding of that reality is not an issue, because it claims there exists a rather simple mapping between the two. Rationalistic tradition believes that our ability to intelligently act in the world around us is due to the mental images or representations of the real world that we have in our minds. It claims that we think in terms of objects and their properties that are (more or less faithful) models of objective reality. For example, if an engineer says, "this beam is cracked", the terms "beam" and attribute "cracked" apply to some objectively present beam that objectively is cracked. Knowledge is storage of such representations. When we need to think about a problem, we retrieve a relevant representation (or, as Minsky would put it, a frame of related representations) and adapt it to the current situation.

This tradition can be traced back to Aristotle, who introduced a three-way distinction between *words*, "*experiences in the psyche*", and *things*. Early in this century Ogden and Richards (1991) proposed a similar schema in the form of the Ogden meaning triangle. It connects words, concepts and things. Each of the points on the triangle indicates a separate component that may be involved in thought or communication. The **object** is any entity from some real or imagined world about which an idea is held. The **concept** is the idea or thought of the object as held in the mind of a person. The **symbol** is an auditory, visual, or other form of utterance that is taken to stand for the object when communicated as part of a language. Any one of these components may be present without the others (Sowa, 1991). Such understanding of the human mind has provided the theoretical foundations for information and database systems development (Sowa, 1984).

3.2 Human, animal and machine intelligence are based on similar mechanisms

These ideas have also been adopted by the AI and cognitive science community (Gardner, 1987) that placed great hopes in the possibilities that computers might become just as intelligent as humans are. It has been suggested that intelligent systems (humans, animals and computers) achieve their intelligence by manipulating symbols of real world items; that symbol manipulation processes are similar in all such systems. Cognitive science postulates that because computers are symbol manipulating systems, they can achieve intelligence as well.

Programming is letting the computer know the concepts we have about the world. The symbols used in the computer (zeros and ones) will be different from what humans use to symbolise the concepts (sounds, words, graphical notation) but, so the theory claims, this is not important as long as the basic mechanisms are preserved. Using programs is mapping real world objects into computer's symbols and back. Such an approach is also the foundation for contemporary database designs and standards such as ISO-STEP(1994) and ISO-IRDS(1993). It is the foundation for the product modelling approach to computer integrated construction. Ekholm and Fridqvist (1998) have used this perspective to propose a structure of an information system for innovative design.

4 Hermeneutic constructivism

Hermeneutic constructivism (Winograd, 1995) builds on the philosophy of Heidegger (1962), findings in neurobiology (Maturana) and linguistics (Austin and Searle) and offers a radically different perspective on the workings of human mind. The workings of the mind and of model manipulation software is so different that the second really cannot achieve intelligence or creativity.

Hermeneutic means "interpretative" - meaning is not objective but achieved only through interpretation. **Constructivism** claims that truth is constructed on-the-fly and is not static. Some findings in neurobiology and psychology confirm that the conceptualisation - summarising of sensory data into higher level concepts, does not happen during store but during the recall.

The **key points of hermeneutic constructivism** can be summarised as:

- Intelligent behaviour is not based on mental representations of real world. It is pre-reflective, pre-rational, based on the being-in-the world, on "throwness" into the world, and not on being-in-the-model or being-in-a-theory.
- Problem solving is not a search in a space of potential solutions. The essence of intelligence is finding a solution outside the predefined search space.
- Communication is not information exchange - it is the negotiation of commitments among people.

4.1 Intelligent behaviour is not model based

In the core of Heidegger's philosophy is the understanding that the basis for our everyday action is the ability to act pre-reflectively when "thrown" into a situation. He claims that reflective thought about objects and properties is derived from preconscious experience of them as "ready-to-hand". The essence of intelligence is "**throwness**", not reflection. This is contrary to the tradition, which would consider reflective analysis of a detached observer as the basic intelligent behaviour.

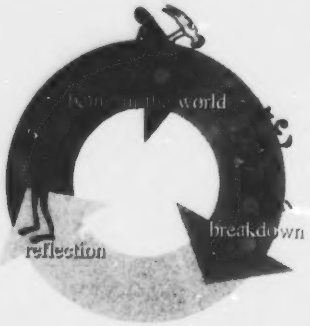

Fig. 1: The reflection loop

To hammer a nail, Heidegger argues, we do not require conscious reflective knowledge about the physical properties of a hammer and the physics of hammering. The tool is **ready-to-hand** and we just hammer the nail into the wall. Similar pre-reflective actions can also explain the so-called "intuition", "insight" or plain "common sense" that are sometimes used by the designers or engineers to explain their creative process. A good idea just pops out of nowhere, often while we managed to get out of a theory - while walking a dog or riding a bus. The solution is not a result of a systematic search in the set of potential solution. "*The essence of intelligence is to act appropriately when there is no simple pre-definition of the problem or the space of states in which to search for a solution*" (Winograd and Flores, 1997, pg. 98).

Heidegger does not claim that reflective action does not take place. On the contrary - in the case of "**breakdowns**" such as problems, difficulties we begin to examine the world in terms of objects and properties (Figure 1). We do this because, according to Frankl (1989), the main driving force of humans is the *"Wille zum Sinn"* - the will to meaning.

The models and theories developed after breakdowns have both positive and negative implications. They enable that we avoid similar breakdowns the next time - and not only we, who defined the model or the theory - others as well. They do not need to share our expertise that was required to create a model or theory, they simply need to follow the procedures as we defined.

In the Middle Ages, when structural mechanics theories were almost non existent, it took a genius to build a large. Today any structural engineer, even a stupid and lazy student should be able to design one, even an expert system could do it. Indeed, having theories and models available to insert values into, helps the routine, day to day work a lot. On the other hand models and theories cause blindness.

4.2 Models cause blindness

The very instant we begin to think reflectively about a situation and analyse it in terms of objects and properties we disconnect ourselves from the *being-in-the-world*, we are not *thrown* into a situation any more. We limit our view of the problem to the one that can be expressed by the objects and properties we have adopted, and become blind for all other possible solutions. For example in the bridge selection expert system, only the structural designs built into the expert system can be "designed". Even human engineers, when looking at the problems with a closed mind, show symptoms of blindness. Blindness is best demonstrated by parametric design where the set of potential solution is the number of permutations of different parameter values. This creates blindness for all other kinds of possible designs. The world is not made of objects with properties

Physics tells us that the world is made of atoms and he subatomic particles. Larger objects with properties are human inventions, human conventions, and do not exist outside of human procedures; procedures that did break down. A hammer does not exist as a separate object unless there is a problem with it, unless there is a breakdown. While we hammer without problems we do not experience the hammer as a special object. Because objects and properties pop into existence only if there is a breakdown, things do not have properties independent of the interpretation and the context of the breakdown.

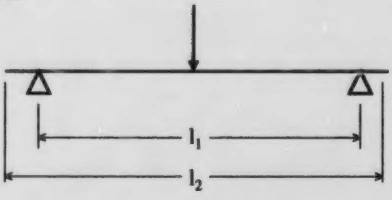

Fig. 2: Lengths of a beam

According to Heidegger, for example, a concrete beam does not have a modulus of elasticity (E). This sounds a bit drastic but when you think of it - in Roman times when they did not know about E, beams did not have that property. It became meaningful to talk about E only in the context of certain structural mechanic theories. Objectively, E does not exist; objectively beams do not have length. Length can only be established within a context where the users share a common understanding of the length of a beam (Figure 2). This does not mean, of course, that there is not a certain amount of concrete in a certain location in the universe

5 A hermeneutic perspective on product models

5.1 It explains some problems

There are several issues related to product modelling that can be explained with hermeneutic constructivism (HC):

- Most research projects define their own conceptual product models. In the light of HC it could be argued that because conceptual models are subjective, it is easy to model one's own understanding - much easier than adopting someone else's.
- Defining a common conceptual model, even within a small research team is difficult and leads to endless discussions. If conceptual models were objective and could be based on some hard scientific facts about the domain, this could be used as an argument in the discussion. But often they are not - there is no reality out there to check the models against.
- There is no way to prove a model correct or wrong, better or worse, except for its internal structure. All one can say is that it does or does not meet some requirements. This is similar to the evaluation of the works of an architect - among the proposals that meet the requirements a committee select the most "beautiful" one. In engineering, conditions of satisfaction are defined much more unambiguous - meet the requirements at lowest cost. Therefore the author claims, conceptual modelling is, to a large extent, art, and not science. If we believe Heidegger, it theoretically cannot be made into pure science.
- The conceptual product models are to an extent similar but essentially different to each other. All are said to be correct, successful, applicable, etc. Usually, in science, several people come to the same result independently.

5.2 Doubtful extrapolation of research into industry

In the 1980s expert systems were considered a very promising information technology. Today they are often used as an example for failure of a technology. What the product modelling community should be worried about is that there are some similarities between the product modelling approach and expert system techniques.

Both approaches believed that it is possible to create a computerised representation of the knowledge (expert systems) or information (product models) in a given domain. But it seems close to impossible to define complete models that would really make them useful in the practice. In research prototypes it has proven possible to define partial models or 80%-of-the-time-right expert systems. It has been argued that it is a rather simple effort to extrapolate the research prototype into an industry strength application. In the case of expert systems the critics have argued that to cover the remaining 20% the enormous amount of background and common sense knowledge would need to be computerised (Dreyfus and Dreyfus, 1988). In the case of product models the issues are similar. The modelling of data needed to support the activities for which physical models exist is unproblematic. But the modelling of data that appears in activities that are handled in an ad-hoc basis, using common sense, improvisation etc ... is not possible. Civil engineering is a domain where quite a few tasks are handled in such a way.

5.3 Product models are interpretations not representations

In section "Modelling" we have shown that product models are anthropotechnical models. They are not models of objective reality but of an individual's interpretation of that reality ... achieved in a given context. The exceptions are those parts of the product model that are defining a data model for a scientific theory.

When developing a standardised product model, a committee can achieve a common interpretation and later impose it on anyone using the standardised product model. But because the interpretation is a function of the context, domain, breakdown, culture etc. it is unlikely that the standardised model could match it all. To create complete models the entire cultural context of humanity should be modelled.

5.4 Product models should leave room for interpretation

Unambiguity and strict definition of the semantics is usually considered a positive feature of product models. But in the light of the previous section ambiguity, or rather, possibility of different interpretations, is a very important feature of product models, because it lets the human compensate for the deficiency of the model. Usually this can be achieved if the product model contains enough very generic components. For example a "line" can be interpreted as many things, including a wall. A wall, on the other can be used for few other things but a wall.

The same goes for software that implements the product models. Most successful programs are not those that try to fully model the domain in which they operate, but those that implement the most generic concepts of the domain and leave plenty of room for modification and evolution; not necessarily by adding less generic data structures but by leaving the user the freedom of interpretation of the existing ones. For example, generic tools like AutoCAD or Word, are more popular than specialised ones, like ArchiCAD or SGML editors. The seconds have a much higher level of semantics (of buildings or texts) but in.

5.5 Co-existence with unstructured data

In the early days of computing, when memory was precious, data was carefully structured. For example years were represented with the last two digits only. Structured, indexed or classified data also helped the computers to be more efficient. Today, both RAM and disk space is cheap, and the CPUs are still doubling their speed every 18 months. What remains expensive is the human effort to structure that data, both during software development and during software use. It has been estimated that in the future the amount of unstructured data handled by computers will continue to increase. We can assume that the structured part of building product data will constitute a smaller part of all data related to a building product. To be practical, product models must include or relate-to the majority of unstructured data.

5.6 Product models for creative design: a contradiction in terms

Model based software can support routine, bureaucratic processes that fit into the schema designed during software development. But can model based software support creative design? In the light of hermeneutic constructivism, the term "conceptual model for creative design" is a contradiction in terms. Only designs that fit into the model are possible. Creative ones, by definition, are those, that step out of the predefined conceptual model.

What has been regarded as an answer are "extensible" models created in such a way that the schema could be extended at runtime, such as the EDM (Eastman, 1992) and models that would support dynamic schema evolution etc. But does this really make any difference? It is not sufficient if the user can add an attribute "Poisson's number" to the schema and some rather simple constraints related to it. Of what use is it, unless there is code in the finite elements program that implements it? In other words, it takes a programmer to extend software, evolve the product model and enable a new generation of designs - routine designs within the scope of the extended software.

This does not mean that computerised tools for creative design cannot be created. If we accept the idea that that being-in-the-world is important for the human mind then we must make sure that software does not stand in the way. Therefore pen and pencil are popular with the architects and engineers in the initial stages of design - because they are not in the way, they are not limiting the creative process. Creative design can be supported by software that provides the freedom of interpretations. Software based upon complex product models is typically not like this.

6 Conclusions

A theory called hermeneutic constructivism has been presented. It exposes the limits of product modelling technology:

- Conceptual models capture a part of relevant data for the building processes. The common sense, social context, and general information should not be underestimated.

- Conceptual product models are subjective interpretations. This should be kept in mind while defining or discussing them. They are not right or wrong but appeal to more or fewer people.
- Models cause blindness. Creative work is least hindered by models that are so generic that they are not blinding or limiting.
- The success of research prototypes is relative. Product model and expert system technology faces the explosion of background knowledge and the richness of possible contexts when tried in an industrial environment.

Based on this some research directions for construction IT include:

- Coexistence of structured information and unstructured data; non-model based technologies; technologies that rely on the human to interpret the data.
- Multiple models are not necessarily bad. They confess the fundamental nature of anthropo-technical models.
- Software that does not build a barrier to engineer's being in the world but rather enhances it (like VR, telepresence, multimedia etc.).
- Communication software to support commitment negotiation instead of information exchange (Internet, groupware, collaboration, etc.).

Common to most of the listed approaches is to place the human, not product or process, into the centre of attention of construction IT. This is achieved by confessing that his view on the problem is subjective, that he operates in huge day-to-day context, that creativity can be hindered by models and theories and that the essence of human work is not processing, but functioning in a social context.

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PART TWENTY-ONE

PROCESS MODELING

267 MEASURING INFORMATION INTEGRATION IN PROJECT TEAMS

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Abstract

Integrated project information is the goal for many clients and their project teams. In theory, the aim is to use IT to support a seamless electronic process in which data are entered once and where no manual intervention interrupts the flows across the different life stages. In practice, IT has been used largely to reinforce existing work patterns that fragment the team's efforts. So far, IT has delivered limited benefits. A study of integrated project information has been completed on 11 building projects across four European countries. Degrees of integration of project information have been measured and used to derive some measure of the extent to which project teams are bound together by the use of IT. This paper summarises the 11 case studies, by revealing the extent to which IT has been successfully applied to support integration. The findings provide pointers to the future application of IT by project teams. In this regard, the active interest of the client in the project and its IT infrastructure is emphasised.

Keywords: IT, integration, project information, project teams, process models.

1 Introduction

The use of IT on 11 construction projects has been studied to establish the type of IT being used and the degree to which information was integrated. This refers to the extent to which the exchange of information between project participants occurs seamlessly without any re-keying of data. The combined value of the projects studied exceeds 2 billion Euros.

Durability of Building Materials and Components 8 (Volume Four). *Edited by M.A. Lacasse and D.J. Vanier.*
Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17743-9

This paper describes the findings from the 11 project case studies and provides clues to the more effective use of IT at the project level, where the client's objectives must be satisfied by the combined efforts of human resources, materials, mechanical assistance and IT support.

2 Project life stages

All stages in the building life cycle were considered – see below. Comparison was made on the basis of this structure, taking account of different procurement strategies, and the extent to which information flow was IT enabled. All 11 projects were believed to reflect at least good use of IT. The following stages were covered.

1. Inception
2. Briefing
3. Feasibility
4. Concept design
5. Scheme design
6. Detail design
7. Tender documentation
8. Estimating and tendering
9. Evaluation of tenders
10. Off-site fabrication/prefabrication
11. Delivery/logistics
12. Production/assembly
13. Testing, commissioning and hand-over
14. Operations/facilities management
15. Re-use/demolition

3 Method of study

The study was loosely based on benchmarking methodology (Leibfried and McNair 1994) and relied principally on interviews with key project participants. It was agreed that all information flows reported by them should be regarded as necessary to the projects in question, but that detailed recording of the information was outside the scope of this study.

Project co-ordinators were interviewed in order to obtain a complete (or as near complete) picture of the information flows, their frequency and the kind of IT being used. Each project was visited, on average for two days: first, to get the general impression of information flows and IT use, and second, to make detailed notes and to refine the analysis. Further days were spent in preparing and validating the resultant functional models.

Interviews began by considering the extent to which the list of generic stages applied to the project. The technique used to assist in the analysis and the subsequent presentation of the 11 project process models is IDEF0. This is used to document activities, their relationships and their associated inputs, controls, outputs and mechanisms (ICOMs). This was supported by computer software: originally Ai0win, but subsequently BPwin. Both are based on the US IDEF0 Federal Information Processing Standard for function modelling.

The basic notation of IDEF0 has however been modified for the purpose of this study to aid clarity in the analysis and presentation of information. Input and outputs are shown As-Is, that is, as the actual flows into and out of activities in the way they occur in reality. Controls and mechanisms have, on the other hand, been simplified so that the various participants, organisations and authorities that have any bearing on the projects (and hence the process) are represented as controls; mechanisms remain to cover mostly IT elements and other tools.

4 The projects

Six of the 11 projects are briefly described below.

4.1 Out-of-town shopping mall

This is one of the largest building projects currently being undertaken in northern Europe and is being procured under a modified design and build arrangement. The architect was novated to the construction manager during the latter stages of design. It is a fast track project, with a large body of design staff and has faced a lot of pressure, not least in surviving a difficult planning application. Local sensitivities have been a major factor and constraint for what is said to be the last project of its kind in the region.

4.2 Speculative housing

Innovations in practice, as well as in the use of IT, are reflected in this case study, the design and construction of a medium sized housing project. A striking feature of this project is that of a single source of responsibility under the control of a developer-builder. The adoption of an innovative procurement method took the place of practices that were long considered in need of change. A good example of this was where management of the supply chain had to be completely overhauled. Suppliers became partners in the process and, as part of the new working relationship, were given electronic access to the project database. This innovation enabled the project team to eliminate many non-value added activities that otherwise characterise much of traditional procurement.

4.3 Office complex

Built to support the client's expansion into financial services. The design commission was won in competition for a scheme that, subsequently, changed significantly. Although the client could be regarded as informed or expert, that appears to be true only in the case of its core business. The client was inexperienced and unsure of requirements. This necessitated a close interaction between the design team and the client. Changes very late in the day were a feature of this project. The architect was novated to a management contractor during the later stages of design.

4.4 Public-private partnership detention centre

That was the first of its kind involving the use of several innovative approaches. Major projects can create many challenges. Complexity and a novel form of procurement were just two challenges facing the project team on this large building project for a public–private partnership. Added to this was a diverse and culturally varied project team. The result was a challenging project. Perhaps for these reasons, effort was concentrated more on integrating people into effective teams than achieving the highest practical use of IT.

4.5 Manufacturing facility

This is a major project with a *hands on* client and is based on a management contract. Very high levels of services were required, with extensive clean room technology. The project commenced in November 1996 and suffered a slight setback through the current economic problems in Southeast Asia. Work on the site was, in fact, suspended between during the first quarter of 1998. Completion is scheduled for early 1999. The project is welcomed locally as it is expected to provide high levels of employment within the area.

4.6 Headquarters building, car park and related facilities

For a car manufacturer which is let as four separate contracts. The headquarters building, a 40,000m^2 development, was the subject of an internationally invited design competition. Considerable effort was expended during the competition phase, which provided the basis for the subsequent design commission. The client novated the contract to a developer, with the intention of leasing back the development on completion. The contractor that took on the design and build contract re-let the consultancy contracts, although the developer retained the original consultants in an advisory role. The project reflected a very demanding brief and client and one where the physical location of the project was bound to cause some difficulties. Procedures were highly detailed and somewhat complex. The design commission was a joint venture with partners from two countries.

5 The projects' use of IT

5.1 Out-of-town shopping mall

This project's greatest achievement is probably its control over a large and intensive work programme, involving a large number of people and organisations. The construction manager's use of an in house developed system of information, cost and change management ensured that information flows were controlled and directed to those who needed them. This was an information management application on a large scale, with impressive savings demonstrated in the use of IT over traditional means for communication and the transmission of drawings etc. No organisation was allowed to fall outside the IT sphere or regime. This meant that even the smallest of contractors and specialists had to fall into line and enable information flow to be fully electronic. There could be some criticism of the narrow focus of this IT supported process; whatever it is, the word focus is highly pertinent. IT was used to get on top of a large problem and reduce it to more manageable proportions.

On the downside, the project suffered from what appeared to be too protracted a design phase, where information was developed very incrementally and where some input (especially those in relation to constructability) occurred late in the day. The impression was of a project trying hard to keep up. IT made sure that, at the very least, the process stuck to the schedule.

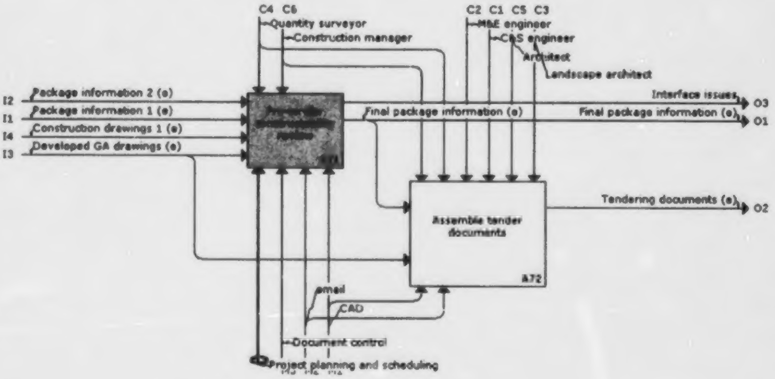

C4
C6
Quantity surveyor
Construction manager
C2
C1
C5
C3
M&E engineer
C&S engineer
Architect
Landscape architect
I2
Package information 2 (e)
I1
Package information 1 (e)
I4
Construction drawings 1 (e)
I3
Developed GA drawings (e)
Final package information (e)
Interface issues
O3
Final package information (e)
O1
Assemble tender documents
A72
Tendering documents (e)
O2
email
CAD
Document control
Project planning and scheduling

Fig. 1: Constructability studies are vital, but should not be too late in the process (The letter (e) after the name of a flow indicates that it was electronic)

5.2 Speculative housing

This project exemplified the concept of integration through a re-engineered process that used significant IT to achieve lower production costs against demanding time-scales. The project team was able to report substantial reductions in programme time when compared with more traditional procurement, including its own previous work.

In overall terms, this developer-builder claimed a near 50% reduction in time spent on design today, compared with earlier projects. Particular gains arose from the ability to make changes to the design once only and an ability to communicate them rapidly to those affected. CAD was a key technology for this developer-builder and one that was used to build object-oriented models embodying information about the process. The intention was that these could ultimately be evolved into product models serving the wider needs of the project team, manufacturers, suppliers, the client and end users.

During the project's design, checks for consistency in detailing and clash avoidance – especially in the area of engineering services – also meant that prefabricated components could be manufactured in the belief that few problems would arise on site. This latter aspect was important since the time spent on site had been compressed to the point where there could be little tolerance for delays caused by errors and inconsistencies. Bringing manufacturers and major suppliers into the project during the earliest of stages helped to co-ordinate work to the extent that the team adopted the goal of zero errors in component delivery and assembly. Comparison of the use of IT against the earlier manual process showed that quality, reliability, accessibility and re-usability of information was significantly better.

In many respects, this project has moved a long way towards the ideal of making construction more like a manufacturing process. By applying IT to a re-engineered process, this developer-builder was able to progress towards the goal of integrating project information, which, under more traditional procurement forms, would have been very difficult. The developer-builder is intent on extracting further gains, as part of a culture of continuous improvement, on top of an already significant payback.

5.3 Office complex

The client relied heavily on the architect's traditional plan of work and the IT tools that supported it. A lack of real pressure for IT use by the client and 'constructor' meant that more reliance was placed upon the architect's own preferences in regard to the use of IT. This did not necessarily imply a great or innovative use of the technology. Indeed, there are elements of the process where streamlining of working practices could have been achieved had the client and rest of the project team been more IT aware. IT use supported the control of documentation generally and the production of design information in particular.

The client was heavily involved in many changes to the design. However, the absence of a quantity surveyor, as part of the design 'loop', meant that progress in evolving, developing and refining the design was hindered and was not always as planned.

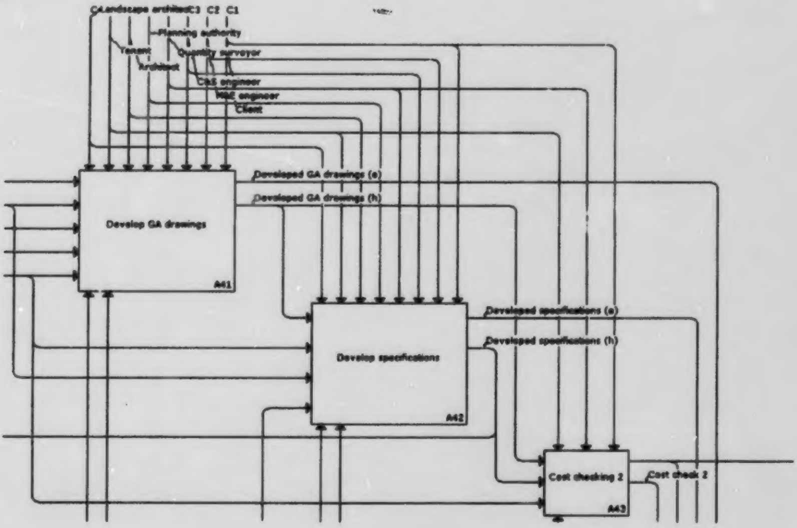


Fig. 2: Quantity surveying cost checking function hindered the free flow of information

5.4 Public-private partnership detention centre

IT was present in many forms – desk top PCs, email and database management – though there was little linking and sharing of information. That said, the project was viewed as a success, against a tight time-scale, strict budgetary control and a very demanding client. The nature of the project, in particular its intended use, meant that security was an important factor weighing on the project team. The imposition of rigorous procedures, designed to ensure confidentiality and security on what was also a politically sensitive project, meant that IT was felt to present too great a risk for the project team.

Limited electronic exchange did take place between parties, for instance amongst the designers and with the client body, but even these did not amount to a significant attempt to integrate information on a project wide basis. The demands of the project were probably thought to be enough without having to cope with the uncertainty of IT. Even so, the opportunity to enforce better communications between the various actors through, for example, projects wide email and drawing exchanges was passed up. Project team members were acutely aware of the penalty for failure on the project and so anything that was unproven was unlikely to be adopted. Given that the project was the first to bring the consortium together, there was probably no obvious basis upon which to implement an information management strategy.

IT was used in many different ways, but most was in supporting the disparate working practices of the various participants. As a means for exchanging information, IT was rejected for the reasons given above. The co-location of project team members helped team building, but did not necessarily make for an efficient process. Meeting deadlines and working within budgets are not conclusive proof of an efficient and cost-effective process. Concentrating attention through the actions of project personnel may not represent the most efficient use of human resources, but it can get the job done. The fundamental issue is therefore one of whether or not IT is necessary for integrating the project team. On the face of it, there is no evidence to support this proposition. However, there is no evidence either that efforts to integrate project information would have compromised time, quality or security.

5.5 Manufacturing facility

Activities on this project were planned with IT in mind. All drawings were produced on CAD and all documents shared electronically between members of the design team. The client's retained architect, management contractor and the designer each maintained their own servers and LANs for security purposes. All operated with up to date versions of office automation tools and CAD software to ensure compatibility. Limited access was available to areas of all three servers to ease distribution of information. Drawings and specifications were uploaded to the management contractor's server for onward distribution to suppliers and trades contractors (typically on disk). There was, similarly, a transfer area on the design architect's server where drawings were uploaded for distribution. Hard copy documents were still provided in addition to electronic versions.

Internet email was essential to ensuring connectivity with the client (in Southeast Asia) and other consultants located elsewhere in the world. The architect maintained connectivity with head office through an ISDN link to the WAN. Security of data was paramount.

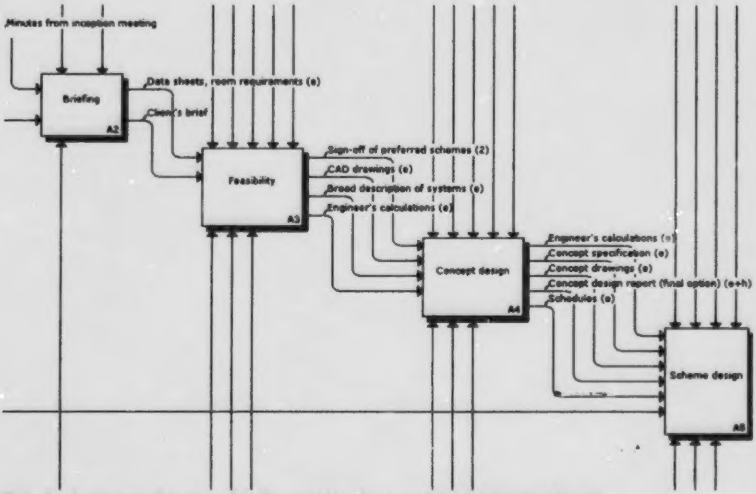

Minutes from inception meeting
Briefing
A2
Data sheets, room requirements (e)
Client's brief
Feasibility
A3
Sign-off of preferred schemes (2)
CAD drawings (e)
Broad description of systems (e)
Engineer's calculations (e)
Concept design
A4
Engineer's calculations (e)
Concept specification (e)
Concept drawings (e)
Concept design report (final option) (e+h)
Schedules (e)
Scheme design
A5

Fig. 3: A strong degree of information integration between stages

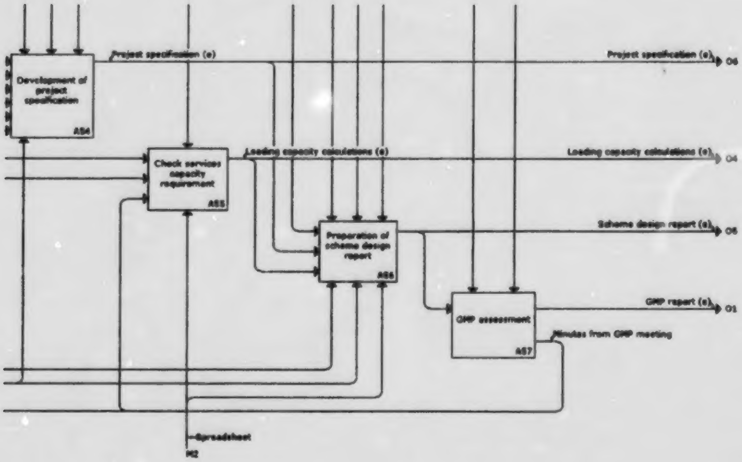
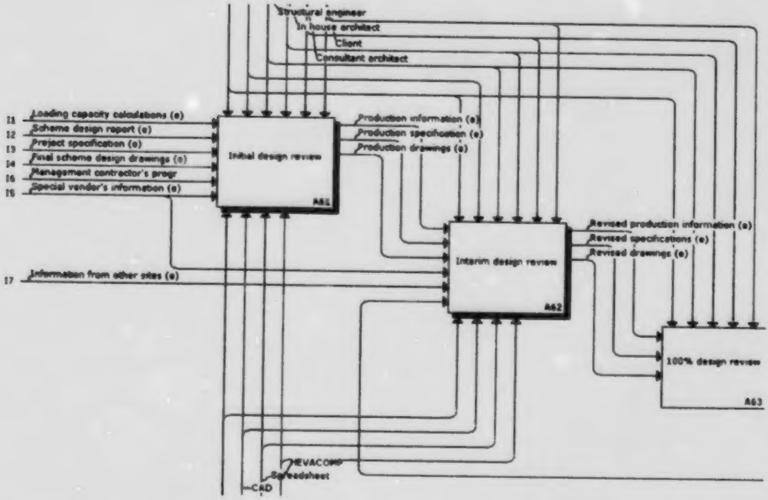

Development of project specification
A54
Project specification (e)
Project specification (e)
O6
Check services capacity requirement
A55
Loading capacity calculations (e)
Loading capacity calculations (e)
O4
Preparation of scheme design report
A56
Scheme design report (e)
O5
GMP assessment
A57
GMP report (e)
O1
Minutes from GMP meeting
Spreadsheet
M2

Fig. 4: Even at a very detailed level there can be good integration

5.6 Headquarters building, car park and related facilities

The project office was based in one country, using the software and CAD facilities available there, and the project was sited in another country. ISDN links were established to the site in order to exchange data with the local design partner and other members of the design team. This was also used to send drawings to a print shop near the site. Data exchange was accomplished by internet email and attachments through the ISDN connection. Internal email in the main design office was automatically forwarded to the external system if the project manager was at the site.

90% of the design and electronic document generation on the project took place at the design office, which had both space and resources. The site office was, on the other hand, very small during the initial phases of the project and connectivity was maintained through a modem link to a laptop computer. Later, the site was connected to a LAN in a new office in the same town as the site.



Structural engineer
In house architect
Client
Consultant architect
I1
Loading capacity calculations (e)
I2
Scheme design report (e)
I3
Project specification (e)
I4
Final scheme design drawings (e)
I6
Management contractor's progr
I5
Special vendor's information (e)
Initial design review
A61
Production information (e)
Production specification (e)
Production drawings (e)
I7
Information from other sites (e)
Interim design review
A62
Revised production information (e)
Revised specifications (e)
Revised drawings (e)
100% design review
A63
HEVACOMP
Spreadsheet
CAD

Fig. 5: Focused involvement of the client and team in design reviews

6 Degrees of integration of project information

Of the 11 projects, the six featured in this paper have their integration index given below, together with a grading. A figure of 1.00 would indicate total integration.

Table 1: Degrees of integration of project information for the six case study projects

Project	Index	Grading
1	0.70	Strong degree of integration
2	0.82	High degree of integration
3	0.55	Moderate degree of integration
4	0.22	Low degree of integration
5	0.70	Strong degree of integration
6	0.35	Modest degree of integration

7 Main findings

1. IT is being used to counteract the problems caused by a lack of integrated project-based work in this fragmented industry, by supporting the electronic exchange of project information. IT is also being used to support innovative methods of building procurement and technology procurement – the highest degree of project information integration is where there is a tendency towards a single source of responsibility for the project.
2. There is strong evidence to support the view that integrating project information is greater when there is a physical distance between project participants, for instance when they are located in different regions. Efforts to effect better communications are helped by the use of IT. Conversely, use is generally lower where project teams are co-located – this working arrangement has benefits for teambuilding, but tends to militate against co-ordination of information and can succeed in building paper bureaucracies.
3. The extent of IT use and, therefore, the degree of integration is influenced by the extent to which the client and 'constructor' see IT as an important factor in achieving project success. Everyone in the value chain must be connected through IT. This is borne out by all projects to a greater or lesser extent. However, the out-of-town shopping mall illustrates what can happen when the 'constructor' ensures that everyone is locked into the system. Even the smallest firm is part of the IT regime: no one is allowed to hinder the smooth, electronic flow of information. Significant time and cost savings were demonstrated from this approach to IT use.
4. Individual project team members may well be prepared to use IT as much as possible, but use or commitment can vary significantly. Each actor must be willing to drive forward the use of IT, if the client is to benefit fully. Where the client appears not to be overly concerned about the need for IT, the resultant desire for the project team to use IT appears less pronounced than might otherwise be the case. In a similar way to the position in 3 above, the client can be instrumental in ensuring that IT is taken very

seriously. In the case of the manufacturing facility project, the client appears to have driven the process hard and that has meant a serious commitment to IT by everyone.

5. Quantity surveyors, acting as the client's primary consultant on cost, are singled out for not being properly integrated into the process. There is a case for appointing only those QSs who can interface electronically with other members of the project team – most notably the designers. There is considerable potential for delays and bottlenecks because QSs are still requiring paper based information. Their physical dislocation from the rest of the design team means that they cannot contribute efficiently to the evolving design. It is a classic case of reaction, as opposed to pro-action. A number of projects show that the QS can be left outside the loop of close interaction between the design disciplines. One reason for this is that the external QS is not employed in a way that actively supports such interaction. The consequence is that the QS exercises a limited role.
6. Design is largely a process of progressive and iterative development of information and detail used to describe the building – the traditional distinctions between the different stages have become blurred. There is good reason to question the several traditional stages that constitute 'development of the design'. Collapsing three traditional stages (concept, scheme and detailed design) into two needs to be examined. Most project teams tend to operate in a somewhat traditional manner. Procedures are geared to a plan of work that seems at odds with some of the objectives and demands of the projects on which it applies. When interviewing project co-ordinators, it became clear that their thinking was often framed in terms of the established plan of work. The implications are that innovative methods might be shoehorned into an inappropriate plan of work. What could appear to be complicated and carefully detailed procedural elements within the models might well be more a consequence of an ineffective plan than an efficient problem-solving function. In this respect, IT has limited potential to streamline and improve the efficiency of the process.
7. Many examples of best practice exist and are noted mostly by the seamlessness that results from an IT-enabled process. There is, however, real danger in that what appears to be a good use of IT might be little more than the reinforcement of a practice that adds little value for the client. As implied in 6 above, faster information is not necessarily better information.

8 Conclusions

The research reflected in this paper is based on the detailed analysis of 11 construction projects. From this analysis, it has been possible to develop an impression of how IT is actually being used and the organisational support and dynamics that enable or frustrate its deployment. Useful, yet simple, lessons can be learned by clients and constructors in stimulating greater application of IT in order to realise savings in cost and time. Before then, there needs to be some refocusing and realignment of the roles and responsibilities of certain participants in the process. In other words, real gains in productivity through IT may not necessarily come from more sophisticated IT, but from participants who are able to apply proven tools and techniques, many of which are low cost.

9 Acknowledgements

The author gratefully acknowledges the support of the UK's Construct IT Centre of Excellence and the various organisations that allowed their construction projects to be investigated as part of a linked UK (Construct IT 1999) and European (Construct IT 1997) study into integrated project information.

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268 REFOCUSING PROJECT DELIVERY SYSTEMS ON ADDING VALUE

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Abstract

The ability to manage a lean supply chain that contains no non-value adding elements is the ultimate challenge. The research behind the paper's findings is based on the production of functional process models adopting IDEF0 methodology to portray information flows, participants, organisations and IT use. Key participants in 11 projects contributed to the research and subsequently verified the models. Analysis was then performed on the models, including checks for consistency and process integrity. A generic model was developed from the best practice elements of all 11 projects, alongside changes in construction procurement and out of sector best practice industrial design and production. The result is a new project generic process model that could form a blueprint for subsequent construction projects. The research continues through modelling and costing different project scenarios so that non-value adding activities can be isolated and eliminated from the supply chain.

Keywords: Process modelling, function modelling, supply chain, value added, value chain.

1 Introduction

Efforts to improve the supply chain in construction are the subject of numerous initiatives within industry in many countries. The potential for process improvement to deliver real savings in cost and time is not lost on the construction industry's clients. Moreover, the prospect of greater consistency in the process, leading to a more certain outcome has raised expectations. Application of lean production principles to the supply

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chain is beginning to show benefits in terms of time, cost and quality improvement, but more can and must be done.

Quite how much improvement is possible will depend on the extent to which the value stream can be identified and manipulated to deliver against client demands. In the absence of this, piecemeal initiatives will produce sub-optimal results. Attempts at optimising a part of the process without understanding the remainder will not result in serious improvement.

An alternative – and the one outlined in this paper – is to model the entire process for a project down to a detailed level. Opponents may simply say that it is too complex a task to be performed and that, besides, all projects are unique. The research has shown that even across different countries (for example, France, Germany, Sweden and the UK) there is too much similarity for this view to prevail. Detailed modelling of the supply chain, in terms of information flows, participants within the process and the tools they use to communicate – especially IT – has already provided many useful insights. A better understanding of how organisations interact at the project level has emerged and will lead to some remedying of long standing failures. Even so, more has to be done to deliver the order of savings in cost and time that have become enshrined in various national initiatives – see for example, the work of the Egan construction task-force in the UK culminating in the report, *Rethinking Construction* (DETR, 1998); and the Swedish programme, *Competitive Building*.

Preliminary research had shown how even the most basic actions are prone to failure because of information that is not communicated when it is needed, in the form that it is needed and to the people who need it. This merely confirms the problem, but does not necessarily provide firm answers. Further examination suggests, however, that the entire infrastructure for delivering a project has to be taken into account. There are simply too many factors and influences that are being overlooked. In this respect, the research is attempting to establish a generic model of the infrastructure for managing the human and other resources on a project, including the IT.

This paper describes the work to date and outlines the next steps for effecting improvement, through the introduction of cost and time data.

2 Proposed generic process model

Elements of best practice within the 11 projects, which are consistent with changes for the better in the industry, have been identified and are presented as part of a generic process model. Of these changes, *managing client's requirements*, *integrating design and construction as a single process*, *value chain management* and *total project management* are major factors in achieving project success.

The search for best practice has been extended beyond construction to other industrial sectors where lessons can be learned for improving the overall process. The generic process model is, therefore, more than just a distillation of 11 projects. It could be used for benchmarking performance and as a blueprint for future projects that can be adapted to suit the needs of individual clients.

Within UK construction are several current initiatives aimed at process improvement. These include the Agile Construction Initiative (Bath, 1998), Egan construction task-force (DETR, 1998) and *The Agenda for Change* by The Construction Round Table (CRT, 1998). All three aim to reduce cost and time dramatically, whilst raising quality and certainty, and are strongly client focused.

In order to achieve the above, and as a reflection of the elements of best practice distilled from the 11 projects, it is necessary to redefine the life cycle stages. This has produced a sequence that is markedly different to that adopted as the basis for modelling the projects. This has occurred for two reasons. First, many activities performed on the projects do not fit comfortably within the original stages, since they attempt to deal with the unique circumstances of a client and/or a constructor-driven process. Second, the original generic stages do not adequately reflect the emerging structural changes outlined above. For these reasons it has been necessary to reconsider the entire process.

3 Redefined stages

Analysis of elements of best practice and their application to construction has produced the following stages for a generic process model.

1. Project initiation
2. Project definition
3. Outline design
4. Advance works procurement
5. Detailed design
6. General works procurement
7. Production
8. Facilities management

This reduced set falls naturally out of the project analyses and includes all the value adding aspects of current process improvement initiatives and established patterns of work. However, it differs in several respects, not least in its use of terminology that is intended to avoid potentially misleading assumptions about what is or is not included. Perhaps the main differences are in reflecting the concurrent and iterative nature of design and its overlap with construction. The proposed generic model also attempts to align more with a process that is client-driven and for which the ultimate deliverable – the building or facility – is just the beginning of the next phase in the business cycle. Whether or not these proposals become adopted depends to some degree on the extent to which identified changes within the construction industry are seen as threats or opportunities.

The stages are now described with reference to the model. Flows of information are not specifically marked as electronic, since all are deemed to be so.

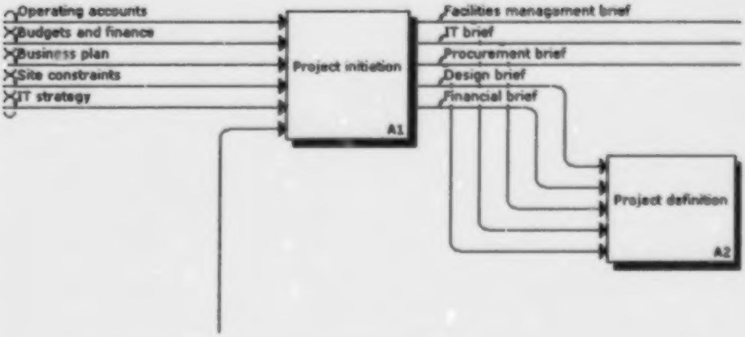

Fig. 1: The first two stages of the new generic process

Stage 1: Project initiation portrays the earliest stages of a project's life where the decision is made to proceed with the idea of a building as a possible solution to the client's needs. From the definition of client's needs, project objectives give rise to briefing. This is often regarded as a single outcome activity, that is, a singular briefing document is produced. Further investigation has revealed how best practice in briefing, both within the construction sector and within manufacturing, considers several different, but interrelated documents. There is the design brief, which will be used, *inter alia*, to express the architectural, engineering and functional requirements of the project. But there are at least three other briefs. Of these, the financial brief is more than a cost plan under the traditional system, since it embodies a breadth of information that is used to set the project on a sound financial footing. Implicit in this is a life cycle appraisal approach to cost planning. Instead of life cycle considerations being added to a capital cost planning approach, they become the dominant features.

Two other briefing documents are produced at this stage, which inform later critical stages in the process. The procurement brief sets out, *inter alia*, the actions, requirements and time-scale for organising contracts and buying work packages. The facilities management brief ensures that matters essential to the successful functioning and enjoyment of the building are brought to the fore and do not become an afterthought. With the growth of public-private partnership projects, it has become clear that the management of the building or facility is a priority concern and one that directly affects funding prospects. Little in the way of technical IT solutions are used or, indeed, needed here. Office automation tools and an effective communications infrastructure will ensure that more order is put into the process.

Stage 2: Project definition is where the form of the project emerges. The first part attempts to produce a design concept that feeds off the design brief. The overall design approach, models and sketches are used to establish proof of the concept. Other primary inputs are the remaining briefs. From this stage emerges a workable design, complete with cost limits and time constraints, i.e. a focus on a design having clear quality, cost and time objectives. Within this stage, separate consideration is given to the several facets of design: architectural, structural engineering, environmental, geotechnical and landscaping. This is also where we see the close interaction of a design value for money function. Life cycle appraisal becomes part of the overall design discipline. It effectively replaces the traditional, external quantity surveying function that ordinarily delays the iterative, convergent development of the design. This is an opportunity for the design discipline itself to achieve greater value for money. This is why there should be a value engineering input. In practice, this could be QSs with an aptitude for design economics and an understanding of constructability issues.

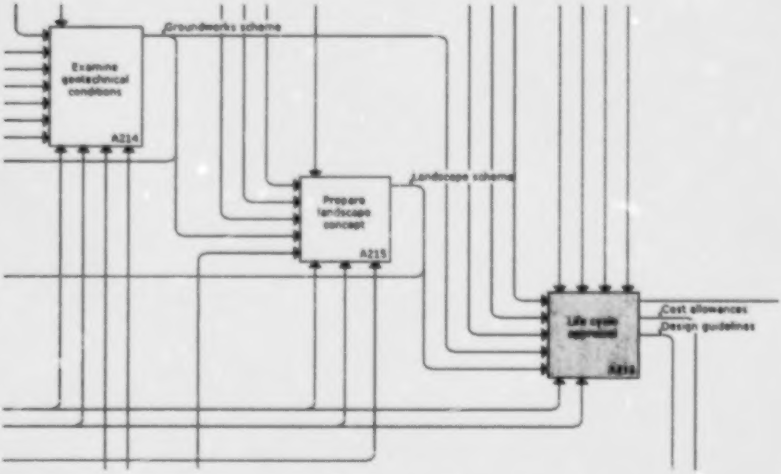

Fig. 2: Life cycle appraisal effectively replaces plain cost planning/checking

The now recognised role of the planning supervisor is brought into establishing proof of the concept. This contribution is integral with that of the value engineer and the design discipline overall. It will also begin the process of ensuring the elimination of accidents. Proof of concept is also where the first applications of value engineering occur – this is something that should be a continuous feature of the design phase. Moreover, it should be design-driven, not left to external disciplines to impose cost and quality cutting exercises.

IT use within project definition is largely a matter of graphics-based systems, (CAD) and GIS. Office automation tools provide the support for most other activities, within an IT infrastructure that enhances communication across the project team.

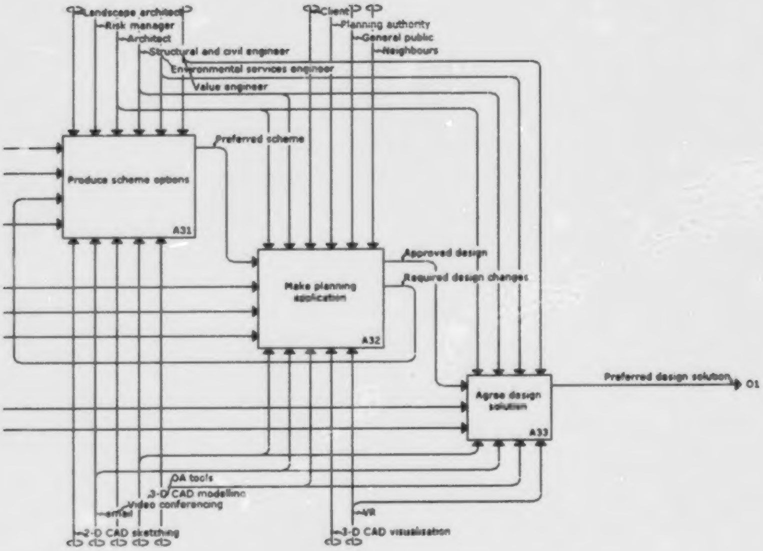

Fig. 3: Using a range of existing IT to establish the concept

Stage 3: **Outline design** is where various design options are explored and from which a single, preferred scheme emerges to form the planning application. Beyond this point a single design scheme can be adopted as the preferred design solution. Throughout this stage are many hidden iterations supported by IT in the form of CAD and other means for understanding how the design will manifest in practice.

Stage 4: **Advance works procurement** deals with the need to commence some parts of the detail design in advance of the generality and which may be the subject of the work of specialist contractors or suppliers. The procurement of such specialist services will have been identified within the procurement brief and arrangements made to negotiate or tender these works. At the operational level, the aim must be to ensure that any external designers do not fall outside the loop of IT use. They must be properly integrated if information is to flow seamlessly. The essence of this stage is that preliminary design will occur in a number of areas. Some practitioners refer to this as *technology clusters* and is reflective of the need to concentrate on major elements of the building having strong connections and for which design and production must be largely concurrent. Five technology clusters are identified here: *frame*, *envelope*, *engineering services*, *groundwork* and *fit out*. IT support is largely the same as in previous stages, that is 3-D and 2-D CAD, office automation tools and a communications infrastructure.

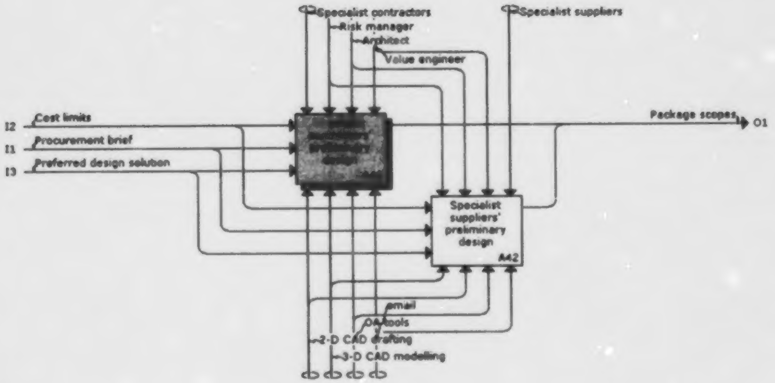

Fig. 4: Specialists must be fully integrated into the process

Stage 5: **Detailed design** draws on developed package scopes alongside the preferred design solution to produce design details. Interface issues are identified and resolved here and a final detail design emerges. This stage is essentially the same as that within the traditional process, except that it integrates the final stages of specialist contractor design with the generality of detail design. As in other stages, there is no differentiation between drawings and specifications. Electronic means have the capability of allowing different forms of abstraction or representation of a design than has traditionally been the case with paper. In other words, the move is away from seeing CAD as a means for simply automating the production of paper drawings and the use of dedicated specification writers. IT uses are, therefore, broadly the same as in previous stages.

Stage 6: **General works procurement** covers what were originally three stages: *tender documentation*, *estimating and tendering* and *evaluation of tenders*. This stage is intended to accommodate the remainder of work packages, although the same basic arrangement could be used for the procurement of specialist works. This could be achieved by linking the procurement brief and preferred design solution outputs from earlier stages to this stage and providing a feedback to advance works procurement. Graphics-based systems are used in the bid package preparation stage, alongside office automation tools and the communications infrastructure which supports the complete effort.

Stage 7: Production recognises the trend towards shifting more of the production off site to factory controlled conditions. Fabrication allows the often long and complex process of off site production to be properly integrated into the totality of the project. It requires a more proactive approach on the part of the project team than has hitherto been the tradition. This stage emphasises also the need to secure evidence of compliance with the specification and other control instruments. Indeed, control over this phase in the overall process will become even more important in future. IT integration is vital. Other aspects of this stage include assembly and commission. These cover the delivery, materials handling, component fixing and the finishing and commissioning of the works. In other words, they are a sequence of activities aimed at ensuring a fully functioning and certifiable building or facility, complete with supporting documentation. This latter aspect is only really likely to be managed successfully if there exists a comprehensive IT infrastructure. Documentation that signifies compliance and provides the means for effecting a smooth transition to occupation is emphasised here.

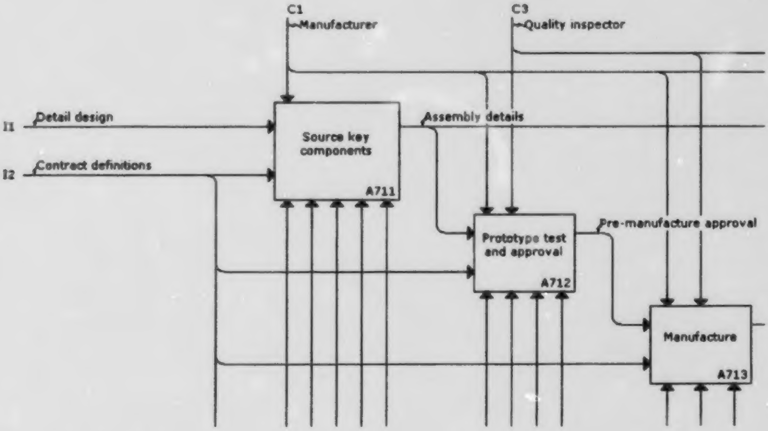

Fig. 5: Off-site fabrication is a key activity

Stage 8: **Facility management** completes the process and provides the basis for a new phase in which the actual demands placed on the building by the client and users can be converted into plans for changes to the building. This stage links directly back to project initiation. Successful development of the design in an electronic form will enable live CAD models to be transferred to the managers of the building or facility without the need for paper drawings. The facilities management brief has the potential to ensure that successful management of the facility is more by design than chance.

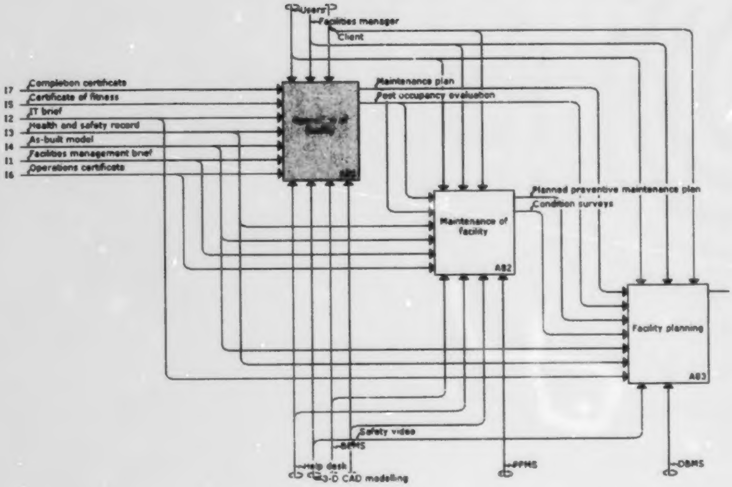
Users
Facilities manager
Client
I7 Completion certificate
I5 Certificate of fitness
I2 IT brief
I3 Health and safety record
I4 As-built model
I1 Facilities management brief
I6 Operations certificate
Maintenance plan
Post occupancy evaluation
Planned preventive maintenance plan
Condition surveys
Maintenance of facility
A82
Facility planning
A83
Safety video
BEMS
Help desk
3-D CAD modelling
PPMS
DBMS

Fig. 6: Retaining the design model of the building to support FM

3 The next steps

Each of the projects has been analysed and presented using a functional modelling tool. The tool has been used to compile a generic process model. This same tool can also be used to capture process time and costs for activities, resources and products.

The initial benefits of using the tool are in organising, modelling and analysing projects As-Is functions and their dependencies to produce a To-Be view of the process. In the next phase of the research, the tool will be used to:

- identify value adding functionality, that is both essential and non-essential non-value added functions;
- track and analyse the cost of the project's activities with automated activity based costing;
- model the project's To-Be functions and their dependencies, from which new strategies for performing those functions can be implemented.

The expectation is that different project scenarios can be modelled and costed so that an optimal value pathway can be found through a project.

4 Conclusions

The research, reflected in this paper, is a partial account of attempts at re-engineering the design and construction process in order to bring about added value. It is largely empirically based and draws out best practice elements from real projects, which have then been incorporated in a new generic model for construction. Armed with base information as to how real projects perform, research effort will now concentrate on refining the process through feedback from new projects using cost and time data. In this respect, IT will be sure to play an increasing role.

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269 COST-LOADED PRODUCTION MODEL FOR PLANNING AND CONTROL

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Abstract

This paper describes a cost-loaded production model that supports integrated project planning, scheduling and estimating and real-time cost and schedule control. The production model integrates product, process, and resource information between all levels of detail and within each level of detail of construction management information. It describes and calculates project schedules and cost estimates explicitly at any level of detail desired by project participants. A hierarchical construction planning, scheduling, and estimating process and corresponding software prototypes assist the user in generating and updating the cost-loaded production model. The main contributions of this work are the consistent representation of component, action, resource, and sequence constraint objects at all levels of detail and the formal planning, scheduling, and estimating processes and mechanisms. These are the two essential components that make the cost-loaded production model possible. The production model enables construction managers to work from general project information to detailed project information, generate detailed what-if scenarios rapidly and control and manage a project's progress on a frequent and precise basis.

Keywords: Project planning, project control, product modeling, process modeling

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1 Introduction

"Was man nicht weiss, das eben brauchte man, und was man weiss, kann man nicht brauchen." (J. W. Goethe, Faust)

Loosely translated, Faust says: "What one does not know is exactly what one needs to know, and what one does know one cannot use." This quote reminds us of experiences on construction projects, where a lot of information about the project was available for crew and project management, but it seemed that we were always missing just the right information necessary to make a well-informed decision. Typically, someone created construction planning and cost estimating information to answer a specific question (e.g., what will be the overall project duration?). At a later time, someone else needed to answer a different question (e.g., how many laborers will we need next week and where will they work?) related to the first question. To answer such questions, we continuously needed to recreate information, aggregate detailed scope, cost, schedule information, and generate more detail as required by the decision at hand. Often, we would quickly make a plan, schedule, or cost estimate to answer a new question. For example, on one project, the project management team created over one thousand separate hand-made and paper-based three-week look-ahead schedules. The main problem is that construction planning and cost information exists in many different forms and places (in planners' minds, on paper, in computer files) and is neither integrated nor easily accessible.

Today, it is still common practice in the construction industry to view cost estimating, construction scheduling, detailed work planning, etc. as separate functions for project execution. The systems used for each function are simply not compatible, and their integration often creates additional work and data and increases the complexity of the project management system. Most proposed mapping schemes (Rasdorf and Abudayyeh 1987, KLR Bau 1990, Gehri 1992) only work in certain situations. The detailed underlying information and the estimating and scheduling assumptions are lost when, for example, detailed cost information is mapped onto cost control accounts and onto master schedule activities. It is difficult to show the interaction between cost and schedule, and to maintain an integrated scope-cost-schedule model when the project design or schedule changes. One can control the cost of concrete, e.g., but it is impossible to manage individual production processes proactively.

In this paper, we present a production model, which considers the needs of planners and builders and supports the creation of cost and schedule models that reflect the realities of project execution more closely than the approaches used in practice today. We propose an integrated planning and estimating process and a computer-interpretable model that support activity generation and sequencing and the estimation of material and time-dependent costs.

We are interested in understanding and modeling the production process of buildings. The production process consumes resources to create a product. The consumption of resources requires time and creates costs. Therefore, the production model integrates a product model, process model, and resource model. Since it models the relationships between product components, process activities, and material and labor resources it avoids the data redundancy found in the approaches used in practice. The hierarchical product, process, and resource models, in addition to the underlying coherent data structures, enable project participants to create individually designed views that focus on the information of interest to them. This paper gives an overview of this project planning and estimating system, summarizes the underlying information model, and contrasts the proposed model with others in the literature. It places particular emphasis on the cost elements of the production model. The work presented here was developed at Stanford University and at the Technical University of Munich. The group in Stanford focused on the construction planning side and developed the Construction Method Modeling (CMM) prototype. The group in Munich focused on time and cost control of construction projects and developed a prototype called POP (Process-Oriented Planning).

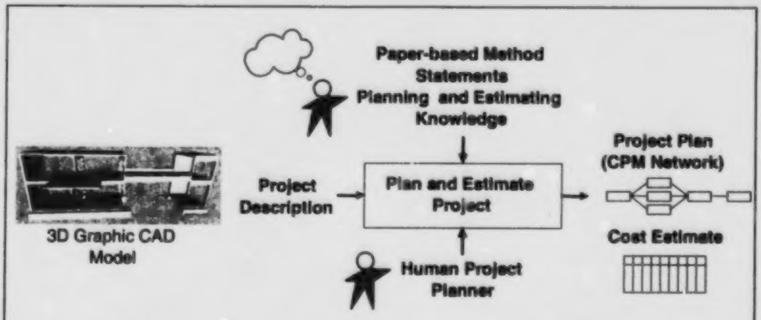
2 Production planning needs

Construction planning, scheduling, and cost estimating are important parts of any construction project. The planning and estimating process and the resulting construction plans, schedules and cost estimates need to support the following needs:

1. Inform project managers about *who* needs to do *what*, *when* and *where*, i.e., determine the *resources* <R> required for a particular *action* <A> on specific *components* <C> or set of components under certain *sequencing constraints* <S>.
2. Provide different project parties, e.g., owners, general contractors, and subcontractors, with <C> <A> <R> <S> entities and their relationships at the appropriate level of detail. For example, represent <C> entities at less detail for owners (e.g., buildings) than for subcontractors (e.g., temporary structures).
3. Support the rapid generation of alternative schedules and estimates based on the exploration of different design and construction method choices.
4. Rapidly estimate and re-estimate the costs for various sets of design and method choices to determine the most cost-effective allocation of resources. Related cost estimates need to be available at several levels of detail.
5. Provide the basis for project control to contrast budgets and target schedules with actual costs and schedules.

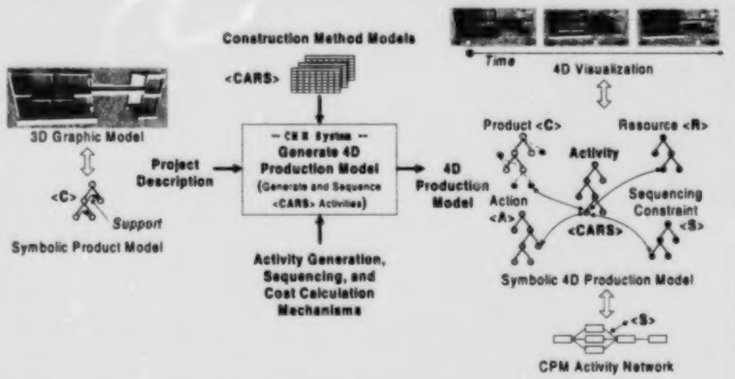
Today, planners base the generation of project plans and estimates on 2D or 3D drawings of a project (Figure 1.a). They use personal planning and estimating knowledge and construction method information to generate the necessary activities and estimate items manually. Software is essentially used to document the decisions and work of the planners and estimators. Typically, commercial project management tools represent schedules as Critical Path Method (CPM) networks and cost estimates in spreadsheets. The current project planning and estimating process and project management software do not address the five needs listed above. The main problems lie with the representation of the output and the planning process.

The output of current systems does not represent *who* does *what*, *when* and *where* in a formal and computer-interpretable way. Furthermore, cost estimates and schedules are usually not integrated, making it difficult to perform real-time progress control or to recalculate the cost of a project rapidly due to a schedule or method change. CPM tools allow planners to model activities with descriptive activity names (Build Foundation) and to associate sequencing relationships (Finish-Start [FS] to Build Wall), work quantities (concrete volume), and resource and cost information (Crew F-3 with its productivity rate) with each activity. With this information, a CPM system calculates activity durations and schedules the project. A planner then interprets the schedule to find out *who* does *what*, *when* and *where*. However, CPM systems represent each of the <CARS> entities of an activity as a name or value only. Therefore, a computer system cannot interpret and reason about <CARS> entities to support the planner in revising and updating activities and their relationships and costs. A planner must manually adjust a plan and estimate to reflect changes in design, construction method, or level of detail. Likewise, an estimating spreadsheet has descriptive names for estimating items but does not contain the information in a computer-interpretable way to support the planning needs listed above.


Paper-based Method Statements
Planning and Estimating Knowledge
Project Plan (CPM Network)
Project Description
Plan and Estimate Project
3D Graphic CAD Model
Cost Estimate
Human Project Planner

a) IDEF$_0$ diagram representing current project planning and estimating process

Fig. 1: Comparison of current and proposed planning and estimating processes. IDEF$_0$ diagrams representing project planning and estimating in current practice (a) and using CMM (b)


Construction Method Models
<CARS>
3D Graphic Model
<C>
Support
Symbolic Product Model
Project Description
-- CMM System --
Generate 4D Production Model
(Generate and Sequence <CARS> Activities)
Activity Generation, Sequencing, and Cost Calculation Mechanisms
4D Production Model
Time
4D Visualization
Product <C>
Resource <R>
Activity
Action <A>
Sequencing Constraint <S>
<CARS>
Symbolic 4D Production Model
<S>
CPM Activity Network

b) IDEF$_\emptyset$ diagram representing synthesis of 4D production model from a symbolic product model in CMM

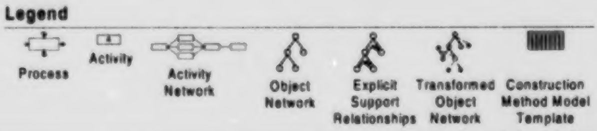

Legend
Process
Activity
Activity Network
Object Network
Explicit Support Relationships
Transformed Object Network
Construction Method Model Template

Fig. 1 (cont'd): Comparison of current and proposed planning and estimating processes. IDEF$_\emptyset$ diagrams representing project planning and estimating in current practice (a) and using CMM (b)

3 Related research and point of departure

Several other researchers have formalized an activity as a <CAR> tuple and used the <CAR> conceptualization to support the generation of activities (Navinchandra et al. 1988, Darwiche ET al. 1989, Jägbeck 1994, Dzeng and Tommelein, 1997). They use the <CAR> conceptualization to generate appropriate activities for each building component in a product model, to link component, action, and resource information, and to automate activity sequencing. However, prior construction planning prototypes do not maintain explicit objects for *components* <C>, *action* <A>, *resources* <R> and *sequencing constraints* <S> at all levels of detail in their product and process models. This makes it difficult to calculate and aggregate costs in a consistent manner on a project and from project to project.

Other researchers have described models that integrate the information necessary for construction management. Froese (1996) gives an excellent overview and discussion of these models. Typically, these models are based on the same classes of objects we have used for the cost-loaded production model (products, activities and resources). They also show the relationships between these construction objects (e.g., an activity uses a resource). Typically, they do not describe how the models will be populated with project-specific information, and how users will update and maintain an up-to-date scope, cost, and schedule model. Without such mechanisms it is, in our experience, almost impossible to enter and maintain the thousands of data items needed to manage a project at several levels of detail.

Building on the <CAR> abstraction and on the conceptual construction information models described in Froese (1996), we formalized a Construction Method Model Template (CMMT) that allows planners to model the activities required for a particular method (Aalami et al. 1998a). Planners define each activity in a CMMT with <CARS> entities. CMM implements a hierarchical method-driven planning process (Aalami 1998b). With CMM, planners can now generate detailed 4D production models from a product model by selecting and applying CMMTs (Figure 1.b). The input to CMM is a design version of a product model. CMM uses the planning information in the selected CMMTs and information in the product model to generate activities with explicit <CARS> entities automatically. The planner controls the levels of detail of the activities CMM generates. For this process we formalized four bodies of planning knowledge: activity elaboration knowledge, activity sequencing knowledge (Aalami et al. 1998c), product model transformation knowledge (Fischer et al. 1998), and cost estimating knowledge. This paper focuses on the essential elements necessary for cost estimating. Prior publications have focused on the planning and scheduling aspects (Fischer and Aalami 1996, Aalami and Fischer 1998).

CMM is implemented with PowerModel by Intellicorp (Mountain View, CA). We tested CMM on several construction projects to verify that it was able to generate production models (viewed as a CPM diagram or a 4D model) that are realistic. The largest test case was carried out in 1998 on a hospital project in Palo Alto, CA. Based on a product model describing over 3,000 steel components of the structural system for the hospital and based on steel erection method knowledge obtained from the steel erector, CMM planned the steel erection work correctly and automatically (Katz 1998).

4 Description of planning and estimating process and information models

Users generate and elaborate cost-loaded activities for the production model with the following planning and estimating steps (Figure 2). For a particular activity (e.g., Build Product at the beginning of planning or Build Wall Pos. 2 after some activities already exist), users choose the construction method they would like to apply by selecting the appropriate CMMT in the methods database. The CMMT knows what detailed activities are necessary to complete the original activity. Each detailed activity knows what component in the product model it acts on, what type of action it carries out, what crew and material resources it needs, what sequence constraints it has, and what one-time costs and productivity rate it has. With this knowledge and with the project-specific information in the product model, CMM generates the detailed activities in the production model (e.g., Place Concrete Wall Pos. 2). It calculates the activity duration by extracting the material quantity information from the product model following the ActsOnComponent relationship (1), by looking up the applicable productivity rate in the CMMT, and by using the duration calculation algorithm for the activity's action type (2). It then calculates the time-dependent costs by multiplying the duration with the crew unit costs stored in the resource library (3). It computes the material costs by multiplying the quantity information from the product model with the material unit cost in the resource library (4). It can now calculate an activity's total cost by summing the material and crew costs and adding eventual one-time costs (e.g., set-up costs) from the CMMT (5). The user can now look at the total project cost or at the cost of producing a particular portion because the system can roll up the activity costs to any desired level (6).

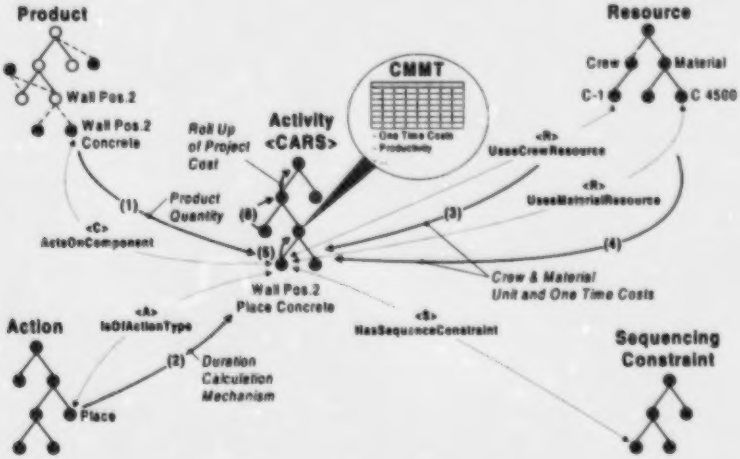


Fig. 2: Generation of cost-Loaded activities for production model

Table 1 illustrates the key attributes for an activity object. It contains the typical attributes one finds in scheduling software (only a few like duration, earliest start and finish are shown here). It contains the attributes necessary for the various types of cost described in the previous paragraph and includes the relations and methods that integrate the product, process, and resource models and calculate the costs of production. Note that this activity model supports an integrated production model that combines scope, cost, and schedule information. Software tools available on the market today only link some of these data items (Staub et al. 1998). For example, one can transfer the quantity information in a 3D CAD model into an estimating spreadsheet at one level of detail. This does not create an integrated production model where a user can generate cost-loaded activities that have explicit bi-directional links to product and resource objects at several levels of detail.

Table 1: Main attributes, relations, and methods of an activity

Activity		
Attributes:		Values:
Id:	LongInt	-
Name:	String	Wall Pos.2 Place Concrete
UnitOfMeasure:	String	M3
ProductQuantity	Extended	10
Duration:	Extended	1 [d]
EarliestStart:	String	01.09.99
EarliestFinish:	String	01.09.99
CrewProductivity:	Extended	1 [h/M3]
CrewUtilization:	Extended	100 [%]
CalculatedTotalCosts:	Extended	9600 [$]
AggregatedTotalCosts:	Extended	-
TimeDepCosts:	Extended	1600 [$]
QuantityDepCosts:	Extended	3000 [$]
OneTimeCosts:	Extended	5000 [$]
:		
Relations:		Values:
<C> ActsOnComponent:		Wall Pos.2 Concrete
<A> IsOfActionType:		Place
<R> UsesMaterialResource:		C 4500
<R> UsesCrewResource:		Crew Type C-1
<S> HasSequenceConstraint:		FS Wall Pos.2 Place Formwork
:		
Methods:		
(1) GetProductQuantity!		
(2) CalculateDuration!		
(3) GetCrewResourceUnitAndOneTimeCost!		
(4) GetMaterialResourceUnitAndOneTimeCost!		
(5) CalculateCost!		
(6) RollUpCost!		
:		

Once users have generated a cost-loaded production model with CMM, the production model can be transferred with an ISO 10303 Part 21 file (STEP Physical File or SPF) into POP (Process-Oriented Planning) developed at the Technical University of Munich (Kuhne et al. 1998a, 1998b). We coordinated the output from CMM and the project information needed in POP to allow users to generate the necessary planning information quickly and to explore several alternatives and update the production model rapidly. POP supports users in monitoring and controlling a construction project. By building on the hierarchical production model described above it supports the typical aggregations used for cost and schedule control while maintaining the original detailed information. This enables real-time cost and schedule control because the cost and schedule information is available at the level of detail and composition needed. The cost-loaded production model allows a user to construct any desired view of the scope, cost, and schedule information because the detailed production information is maintained, product, process, and resource information is integrated at all levels of detail, and each item of information knows from where it originated. POP was tested on a recent freeway project in Germany (Lippert 1999). With little additional effort for data entry (about 15 minutes per day) the site management team was able to monitor and control cost and schedule performance on a daily basis. Because of this real-time and integrated view of cost and schedule, the site management team was able to identify areas of concern while it was still possible to take corrective measures. This was possible because POP models the scope, cost, and schedule information at the level of detail at which site managers collect daily reports from foremen. With its aggregation mechanisms and with its detailed and integrated cost and schedule information, POP can quickly contrast actual cost and schedule data with planned or budgeted cost and schedule data at any desired level of detail.

5 Impact and significance

The production model proposed in this paper is a coherent model that integrates the main production information used to plan and manage a project. This information is grouped into compatible and related partial models describing the building product, the activities or production processes and the resources. This organization eliminates redundancy of scope, cost, and schedule information and allows construction managers to work with subsets of the production information as needed by a particular task while maintaining and using a consistent overall model. As other authors have also noted, the basic relationships between the production model objects are simple. However, the resulting model is highly complex system with a high connectivity between objects and attributes. It is unlikely that software tools will be able to maintain all of these relationships over the course of a project. However, as presented, computer tools can automate many of the routine data generation, integration, and calculation tasks. Our collaboration on this research project and our tests on site have also made it clear to us that information standards like the Industry Foundation Classes proposed by the International Alliance for Interoperability will greatly facilitate the practical use of such integrated information models.

Specifically, some potential benefits of this work for industry practice are:

- Availability of an integrated model that answers *who* does *what when* and *where* at multiple levels of detail
- Rapid generation of cost-loaded production models for different design and construction method alternatives
- Reuse of scheduling and estimating information as projects progress and planning and control needs change

- Availability of "intelligent" schedules and estimates where each activity knows *why* it exists, *how* it relates to other activities, and *how* it calculates its costs

The hierarchical method-driven planning process and the formalization of construction method, planning and estimating knowledge can potentially bridge the gap between site offices and the head office of construction firms. On many projects there is a disconnect between the information the project management team generates and the information generated by the site management team. This is a pity since the experience of field personnel is clearly needed to produce a realistic construction schedule and estimate. No tool exists, however, that allows field personnel to model their knowledge and use it to generate project schedules and estimates with computer software. Today, it is also impractical or maybe even impossible to generate and link plans, schedules, and estimates to the level of detail needed on site on a day-by-day basis. Hence, it is difficult to incorporate field knowledge into a plan useful at the project manager's level. As a result, today's master plans and schedules are often unrealistic and fail to predict activity start and end times and resource needs (Katz 1998). Crews may work on the wrong activities in the wrong areas, slowing overall project progress and increasing project cost.

Given that field personnel in construction are skilled enough to build complex facilities and based on our field tests, we believe that, with the appropriate tool, field personnel would be motivated and able to produce detailed schedules that link to the other schedules at their level of detail and to summary-level schedules. With CMM and POP, superintendents can build detailed cost-loaded production models instead of paper-based look-ahead schedules. Since a model at the day-to-day work level exists they can now match the progress data they already collect on a daily basis with a plan. This should greatly improve the assessment of project progress in a timely manner and simplify payment applications for completed work. They can use information on what happened today to plan tomorrow's work and understand the impact of changes in their scope of work on other disciplines and overall project completion and cost. They can rapidly explore the impact of changes in material and labor availability and study the effect of design changes. The cost-loaded production model also allows them to communicate a schedule as a visual 4D model which helps to identify interference between crews. In summary, CMM and POP help understand the impact of overall project decisions (e.g., a change in completion date) on day-to-day resource allocation and assist in showing the effect of day-to-day progress on overall project progress.

6 Acknowledgments

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270 INDUSTRY FOUNDATION CLASS MODELING FOR ESTIMATING AND SCHEDULING

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Abstract

Industry Foundation Classes (IFCs) developed by the International Alliance for Interoperability (IAI) are general models of a building project that support project information sharing and exchange among different types of computer applications used in the project. The IFCs are developed based on the information requirements from industry processes. The Project Management Domain Committee of IAI's North America Chapter has developed process models of cost estimating, scheduling, and their integration for the purpose of generating the IFCs to support data sharing throughout estimating and scheduling applications. The goal of this paper is to present the models relevant to estimating and scheduling in the IFCs. The paper discusses various modelling issues covering subjects such as costs, construction processes, resources, products, and project documents for work plans and cost estimates.

Keywords: Cost Estimating, Data Modelling, IFC, IAI, Project Models, Scheduling.

1 Introduction

We believe that the evolution of information technology and computing for the architecture, engineering, construction, and facilities management fields (AEC/FM) will inevitably lead towards tools that collaborate through shared collections of information (i.e, models) about AEC/FM projects. A key technology required to enable such systems is high-level standards for representing and communicating project information. Many efforts are underway to develop such standards and establish them as for use throughout various industry segments. Within the building

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construction industry segment, the largest current effort is by the Industry Alliance for Interoperability (IAI), an international industry-based organisation that is developing data standards for AEC/FM projects called the Industry Foundation Classes (IFCs). Release 1.5.1 of the IFCs has now been distributed and is beginning to be supported by commercial software developers while releases 2.0 and 3.0 are currently under development. Although much of the initial focus of the IFCs has been on representing the physical components of buildings themselves (i.e, the product models), the scope of the IFCs also includes non-physical project data such as documents, costs, organisational aspects, schedules, construction resources, and other types of information. This paper focuses on project management aspects of construction projects and the ways that they are being treated within the IFCs. In particular, the paper examines typical project management processes that have been developed in IAI projects: cost estimating, construction scheduling, and their integration. The paper provides a brief overview of the IAI and IFCs. It then discusses the estimating and scheduling processes that have provided information requirements for the IFCs, followed by an examination of the information modelling approaches that have been developed in the IFCs for these applications. The paper concludes with brief comments on other related efforts. Most of the diagrams in this paper are simplified IFC model diagrams in EXPRESS-G (ISO 1991) notation. Most of them are partial or conceptual models where many details have been omitted.

2 Overview of IAI

The IAI is a global, industry-based consortium for the architecture, engineering, construction and facilities management (AEC/FM) industry (IAI 1996, IAI 1998). Their mission is to enable interoperability among industry processes of all different professional domains in AEC/FM projects by allowing the computer applications used by all project participants to share and exchange project information. The IAI's scope is the entire lifecycle of a building project from strategic planning, design and engineering, construction, to building operation. The IAI's goals are to define, publish and promote a specification—named the Industry Foundation Classes (IFCs)—for sharing data throughout the project lifecycle, globally, across disciplines and technical applications (IAI 1998). The IFCs are used to assemble a project model in a neutral computer language that describes building project objects and represents information requirements common to all the industry processes.

IAI members come from AEC/FM industry firms, software vendors, research institutes and universities, professional organisations, and government agencies. The IAI is organised into different regional chapters overseen by an International Co-ordination Council. Current IAI chapters include North America, German-speaking countries, United Kingdom, France, Singapore, Nordic countries, Japan, and Austral-Asian, with more than 700 members around the world. Based on the interest and initiative of the IAI members, a series of domains committees are established within each chapter to represent specialised industry sectors and to provide information requirements for the IFCs from these sectors' perspective. Domain committees include architecture, structures, codes and standards, building services, HVAC, project management, facilities management, etc.

2.1 IFC Architecture and development methodology

The IFCs architecture (Wix and Liebich 1997) is based on layers containing model schemas. The layers include: a resource layer that describes distinct underlying concepts (e.g, geometry, units and measures, etc.); a core layer that defines a kernel meta-model and core extensions to define the basic AEC/FM objects (e.g, projects, products, processes, resources, etc.); an interoperability layer that defines data that is used across multiple domain areas (e.g., building elements, structural components, etc.); and a domain layer that defines detailed data used within specific application areas (e.g, space layout, power and lighting system design, property management, etc.).

Instances of the IFCs are initialised, linked, and assembled by AEC software to create an object model of the building project. In the simplest form of interoperability, the project model is communicated from one software package to another in a data file (e.g, using ISO 10303 Part 21 format) (ISO 1992). Upon receipt of the data file, the software will re-create the project model for further processing and design additions. Currently, there are over 33 commercial software packages that have demonstrated interoperability using the IFC standards (Release 1.5), and several software companies are beginning to offer IFC exchange capabilities within their products.

The IFC standards are developed through IAI projects targeted at specific IFC releases (IFC Release 1.5.1 was finalised in late 1998 and major releases are expected approximately every year). IAI projects are carried out by IAI members who represent two basic roles: domain experts—who contribute their domain expertise and define the information requirements for the industry processes—and technical experts—who provide software engineering skills in information process analysis and modelling. Domain experts are organised into domain groups that meet regularly. IAI projects development follows a process-oriented methodology, which involves the following major steps (Yu, Froese, and Grobler 1998):

- *Processes selection* identifies projects for development based on many criteria relating to industry demand and impact and available resources.
- *Usage scenarios* are developed to define the basic requirements and illustrate their use in real-world examples.
- *Process definitions* determine the specific tasks followed to complete the process and the information flows associated with the tasks.
- *Information analysis* carries out the preliminary information modeling to support the processes.
- *Information modeling and validation* finalizes the information modeling in the context of the entire IFCs and carries out validation of the models, largely through implementation by member software vendors.

3 Process models of estimating and scheduling

Several IFC projects undertaken by different regional domain committees focus on project management related aspects of the IFCs. These include the North American Project Management Committee's Cost Estimating project (Project ES-1 for IFC Release 2.0) (Cole et al. 1998a) and Construction Scheduling Project (PM-1 for IFC Release 3.0) (Grobler. et al. 1998). The PM-1 project includes not only the construction scheduling process, but also the process of initializing a schedule from a cost estimate. Processes to examine extensive estimate and schedule integration, and generic scheduling, have been deferred to future projects, yet all of these efforts are being developed with an eye towards integration and a uniform approach to information. Other construction-related projects are mentioned later in this paper.

3.1 Scope and Scenario

The intended scope for both the estimating and scheduling projects ranges from high-level preliminary conceptual estimates and schedules to very detailed planning. For example, the estimating process identifies the components of the project to be priced out, and then optionally supports detailed work method and resource planning. The scope also includes the task of editing and refining existing estimates and schedules to add detail and incorporate changes as the project progresses. The scope for the process of initializing a schedule from an existing estimate addresses a scenario in which an estimate has been prepared, including work method and resource planning, and this information is used to define an initial set of schedule activities upon which to base construction scheduling.

3.2 Process Models

The process models developed to describe estimating and scheduling were discussed in Froese, Grobler, and Yu 1998. Fig. 1 illustrates a conceptual process model for the integration of estimating and schedule, involving four basics steps (Cole et al. 1998b):

1. *Retrieve Cost & Scheduling Work Tasks*: retrieves work tasks and all their related information regarding resources, logic and duration, etc, generated by both estimating and scheduling process.
2. *Compare Work Tasks*: compares estimating work tasks with scheduling activities (or vice versa) to identify their commonalities and differences.
3. *Identify Work Task Mappings*: identifies work task mapping points, i.e. where a work task identified from estimating should be mapped to one or more work tasks from the scheduling process (or vice versa).
4. *Identify Additional Work Tasks*: After the work tasks are compared and the mappings are identified, additional activities can be identified and created by breaking down a high level task into more detailed ones or inserting a task from one process to the other.

4 IFC Support for estimating and scheduling

The information requirements from the process analysis provide the inputs for IFC modeling. This section discusses relevant portions of the IFCs as they are currently being developed in Release 2.0. (Note that IFC development is on-going, most of the models described in this paper are proposals at the time of writing and final IFC versions may differ).

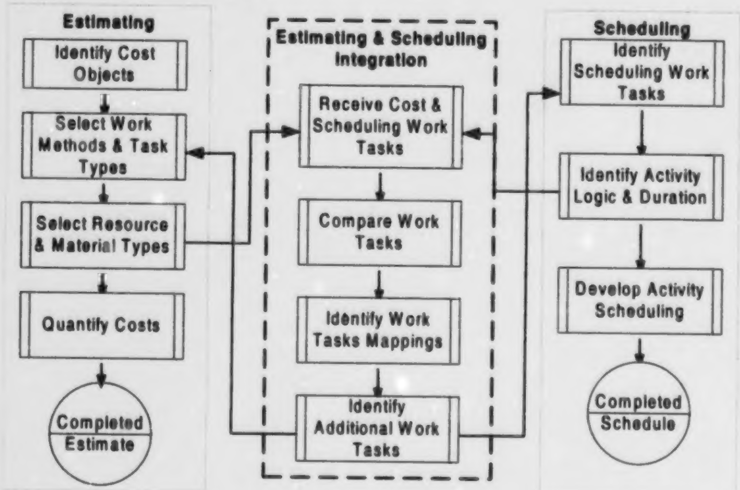
Estimating
Identify Cost Objects
Select Work Methods & Task Types
Select Resource & Material Types
Quantify Costs
Completed Estimate
Estimating & Scheduling Integration
Receive Cost & Scheduling Work Tasks
Compare Work Tasks
Identify Work Tasks Mappings
Identify Additional Work Tasks
Scheduling
Identify Scheduling Work Tasks
Identify Activity Logic & Duration
Develop Activity Scheduling
Completed Schedule

Fig. 1: Process for estimating and scheduling integration (abridged process)

4.1 Construction processes and planning documents

An important aspect of the project management portions of the IFCs is the explicit representation of work processes. While cost estimate items and schedule activities can be associated with work processes, the processes themselves are a distinct element that can be independently described and represented in project models. There are two major entities in the IFCs to support construction processes: IfcProcess and IfcWorkTask (see Fig. 2). The former represents any general actions taking place in completing a work of design, engineering, construction, or facilities management. IfcWorkTask, a subtype of IfcProcess, is intended to describe the work processes that make up construction operations. Information such as construction work methods, schedule dates and duration is defined at the IfcWorkTask level.

4.1.1 Work plans

Any collection of IfcWorkTask instances makes up a plan, represented by the entity IfcWorkPlan. Tasks can be organized in different ways to make up different IfcWorkPlan instances (see Fig. 2). For example, tasks may be organized into a nested hierarchy according to the type of work required to define a plan that supports cost estimating, then the same tasks can be organized into another nested hierarchy according to work locations, possibly with additional work tasks added to expand certain details, to define a plan that supports work scheduling.

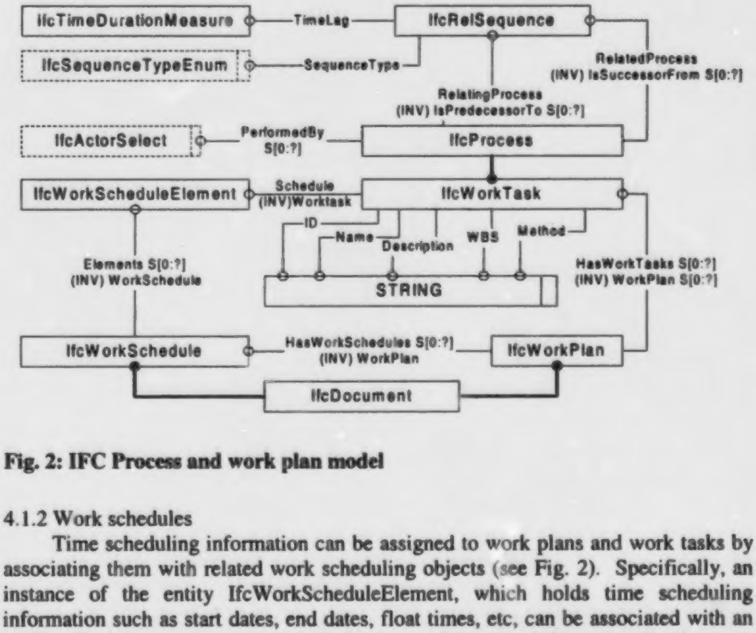

Fig. 2: IFC Process and work plan model

4.1.2 Work schedules

Time scheduling information can be assigned to work plans and work tasks by associating them with related work scheduling objects (see Fig. 2). Specifically, an instance of the entity IfcWorkScheduleElement, which holds time scheduling information such as start dates, end dates, float times, etc, can be associated with an IfcWorkTask instance to represent all the date and duration information for the work task (i.e, the combination of an IfcWorkTask and associated IfcWorkScheduleElement provides the equivalent of a traditional scheduling activity). All IfcWorkScheduleElement instances for a work schedule are grouped into an IfcWorkSchedule instance. One or more IfcWorkSchedule instances can be associated with any IfcWorkPlan. Thus, the related instances of IfcWorkPlan and IfcWorkSchedule comprise a subset of basic planning documents for a project (see Section 4.3 for estimating documents).

4.1.3 Process nesting

Work tasks can represent a process at any level of detail, from broad project phases to very detailed tasks. All levels have the same data structure rather than defining different entities for different levels of activities. For example, an overall project, its development phases, work packages, activities, work tasks, and operations can all be represented as instances of IfcWorkTask. A key requirement for the estimating and scheduling integration process is the nesting capability of work tasks. That is, a work task can be broken down into sub-tasks, but it still remains the same work task itself. In the IFCs, the entity IfcRelNestsProcesses is used to establish the nesting relationship between work tasks (see Fig. 3).

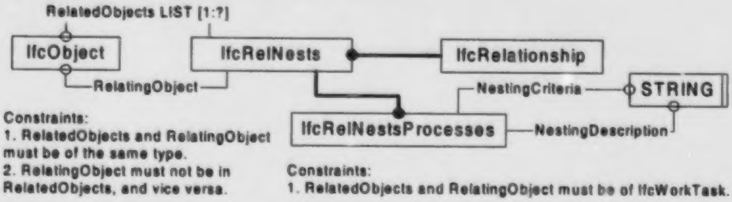
RelatedObjects LIST [1:?]
IfcObject
IfcRelNests
IfcRelationship
RelatingObject
NestingCriteria
STRING
IfcRelNestsProcesses
NestingDescription
Constraints:
1. RelatedObjects and RelatingObject must be of the same type.
2. RelatingObject must not be in RelatedObjects, and vice versa.
Constraints:
1. RelatedObjects and RelatingObject must be of IfcWorkTask.

Fig. 3: IFC Process nesting model

4.1.4 Process sequence

The sequence of processes is defined as an objectified relationship between IfcProcess instances, as represented by the entity IfcRelSequence (see Fig. 2). This entity establishes the link between a successor and a predecessor process, providing a time lag and sequence type (e.g., start-to-start or start-to-finish sequence, etc.).

4.1.5 Linkages with products

One of the central relationships in modeling construction processes is the association between processes and the products upon which they operate. The IFC approach to this is to use an objectified relationship entity named IfcRelProcessesProducts between IfcProduct and IfcProcess indicating the operation type such as install, transfer, operation on, construct, remove, erect, and so on (see Fig. 4).

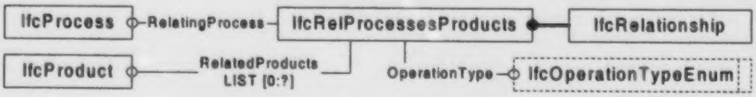

Fig. 4: IFC Model for process and product association

4.2 Construction resources

Construction resources are things that are used to carry out construction processes. The entity IfcResource can be used to represent either types of resources or individual occurrences of resources needed to aid in a construction process. The IFCs currently support five different resource types: subcontractor, construction equipment, construction material, labor, crew, and product resources (see Fig. 5). A crew is a collection of resources (typically a collection of labor resources with some associated equipment and materials). A product resource is used in the situation where a product that results from a work task is used as a resource in another process.

Although it is common to model things such as construction equipment, materials, and labor as resources, it presents a problem in that all of these are things that might also play different roles on a project. For example, a crane might be represented as a temporary constructed product, materials might be represented as design properties or as the basic components in a materials management application, and labor might be represented as part of the organizational information for a project. Further, the characterization of these things as resources, products, etc, can be very dependent upon the perspective of the user of the information. Generally, things should be modeled as "what they are" rather than as "a role they play". Yet the concept of "resources" represents a role that certain things play on a construction projects, and it is difficult to design representational structures that satisfy all these different perspectives. Thus, a subtle but important change being proposed for the IFC Release 2.0 is that IfcResource is interpreted as representing "the use of a thing in the role of a construction resource," rather than representing the thing itself. If only basic resource information such as the names, quantities, and prices is of interest to users of a project model, then IfcResource objects alone are sufficient to represent the information. However, if further information is required about the things that are being used as resources, then the IfcResource instances can be associated to other instances that represent those things (i.e., IfcProductRes and IfcMaterialRes can be associated to IfcProduct objects, IfcLaborRes can be associated with IfcActor instances, etc, see Fig. 5).

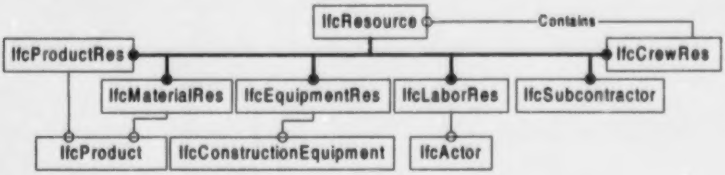

Fig. 5: IFC Construction resource model

4.2.1 Resource and process relationship

Processes use resources. This resource-use relationship is modeled by IfcRelUsesResource as an objectified entity carrying information such as resource use duration, quantity, waste factor, and costs (see Fig. 6).

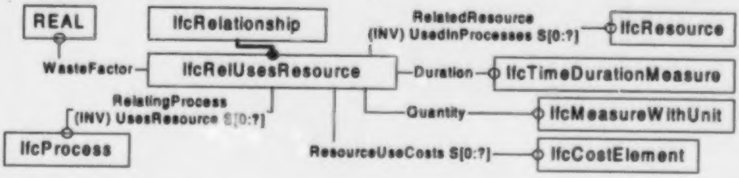

Fig. 6: Resource usage

4.3 Object costs

For cost estimating, different types of costs are assigned to objects such as work tasks or products. This section explains how the IFCs currently handle costs (see Fig. 7).

Costs assigned to objects can only provide meaningful information if the context of the cost values is known. For example, information about whether the unit price of a work task includes material purchases, transportation, material use wastes, equipment uses (operational or rental costs), labor costs, taxes, general contractor mark-up, etc. must be provided along with the numerical cost value. The IFC entity IfcCostElement addresses this by providing cost information, relating to the object being costed, and relating to a cost schedule document (IfcCostSchedule) that describes the context of a list of cost elements. IfcCostSchedule can be used to represent any form of cost list, such as an estimate, a budget, or a unit price table. An IfcCostElement instance can be associated with the objects being costed (e.g, a product, a resource, a process, etc.), through the objectified relationship IfcRelCostsObjects. An IfcCostElement can also be used to group related sub-costs using an IfcRelNestsCostElements relationship.

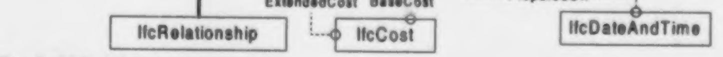

Fig. 7: IFC Object cost model

5 Related issues

The modeling constructs presented in this paper show only a few of the core elements of the project-management-related portions of the IFCs. Many other issues—such as multiple views of work schedules, classification of work tasks, references to external libraries of work types, etc.—are also being addressed. Other IAI projects are also examining other project management applications, including document management, preliminary cost planning, and planning of temporary facilities. Related work is also ongoing outside of the IAI effort, such as the ISO STEP (ISO 1994) and MANDATE (ISO 1998) projects. Finally, portions of the IAI cost model have already been implemented in a demonstration product by one major software vendor (Timberline Software), and others have expressed interest in implementing other portions of the project-management-related models.

6 Conclusions

This paper has outlined current efforts underway within the International Alliance for Interoperability to develop project-management-related portions of the Industry Foundation Classes, an emerging standard for the exchange of high-level project information. The main focus has been on representing work plans, resources, cost and schedule information. We anticipate that the IFCs will soon have sufficient core functionality within this topic area to support real industry data exchange between project management applications, and that significant changes to the way that computing tools are used to support the project management process will follow.

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271 SPICE: IS A CAPABILITY MATURITY MODEL APPLICABLE IN THE CONSTRUCTION INDUSTRY?

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Abstract

Currently the UK construction industry is in search of continuous process improvement mechanisms, in order to improve quality and reduce construction time and costs. Likewise the software industry has been in search of process improvement frameworks, in the past decade. The Capability Maturity Model (CMM), developed by the Carnegie Mellon University, is one of the most widely adopted process improvement initiatives, within the software industry. Many of the basic process improvement concepts in CMM appear generic and could potentially be applied in construction. A recent research project at Salford University set itself the task of investigating if CMM is applicable in the construction industry. The project is titled SPICE (Standardised Process Improvement for Construction Enterprises). SPICE is in search of a systematic step by step process improvement framework for the construction industry. It investigates whether the CMM framework and concepts can be reused in construction. SPICE has conducted several experiments to assess the applicability of CMM to the construction industry. So far the results show that most of the basic process improvement *concepts* of CMM are applicable. However, the CMM *framework* is not applicable in its current form. Much further research is needed to integrate the appropriate process improvement concepts from CMM and other research to develop a process improvement framework for the construction industry. In general the construction industry appears a more mature industry in its shared understanding of customs and working practices. Industry standards and data are more readily available. However, major problems stem from the supply chain arrangements. Also the cost of process improvement initiatives such as CMM may be too high for the construction SMEs, on most projects. This paper discusses the SPICE experiments undertaken to date. It high lights why the CMM framework can not be applied in construction in its present form and suggests future research directions.

Keywords: capability maturity model, construction process improvement, process maturity, supply chain processes

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1 Introduction

Recent reports by Sir Michael Latham (1994) and Sir John Egan (1998) have emphasised the need for the UK construction industry to increase its productivity and improve quality. One method of achieving this would be to improve the management of construction processes. Initiatives such as BPR (business process re-engineering) have a revolutionary approach. BPR is a high-risk process improvement approach. A large number of companies have failed to deliver successful results, using BPR. Generally it is believed that the low profit margins in the industry prohibit businesses from undertaking high-risk approaches such as BPR. Until now the industry has lacked a methodological step-by-step mechanism that enables it to direct its improvement efforts and resources effectively, in an evolutionary fashion.

The Capability Maturity Model (CMM) (Humphrey 1992) is a model developed by the Software Engineering Institute (SEI) at Carnegie Mellon University. CMM is a software process maturity model. This model attempts to quantify a software organisation's capability to consistently and predictably produce high-quality software products. CMM is viewed as "the most pervasive effort to improve the software processes, in more than 30 years ..." (Saiedian and Kuraza, 1995).

CMM is an evolutionary step-by-step framework. The CMM assessment questionnaire allows businesses to assess where they are positioned within the framework. Then the framework provides guidelines on what are their process improvement priorities.

In general, an organisation's actual goal is *product* improvement. The assumption is that an improved process will improve the product in some perceivable way; costs may decrease or quality may rise. This assumed connection is essential to successful process improvement. Herbleb's (1994) analysis shows the link between product and process improvement. It showed that an average of 35% productivity improvements, and an average of 39% post delivery defect reduction was achieved in companies implementing CMM. These figures are promising for the construction industry, which is seeking 30% cost reduction and zero defects (Latham 1994).

The SPICE project at Salford University is funded by the DETR (Department of Environment, Transport & Regions). Its objective is to investigate if the success of CMM can be repeated in the construction industry. Three approaches were used to assess if CMM can be understood and applied in the construction industry. These were: (i) a questionnaire to the construction professionals; (ii) a CMM type assessment of a small architectural practice; and (iii) an experts' panel workshop. These initial investigations showed that the industry understands the value of the process improvement concepts in CMM. However, the CMM framework and assessment tool in their current form are inadequate for the construction industry. This paper provides a review of CMM and reviews the findings of the above investigations.

2 Capability maturity model

The CMM is a five level model (see Figure 1) (Paulk 1993, 1995). The model is designed so that capabilities at lower stages provide progressively stronger foundations for higher stages. Each development stage, or "maturity level", distinguishes an organisation's process capability.

The CMM and the associated questionnaire have two major uses: *assessments* and *evaluations* (Humphrey 1992). With *assessments* organisations use the maturity model to study their own operations and identify the highest priority areas for improvement. Results form the basis for an organisation's self-improvement action plan. Clients use *evaluations* to identify qualified bidders and monitor existing contracts. Results help develop a risk profile that augments the traditional criteria used to select the most responsive and capable vendors.

2.1 CMM levels

The five CMM levels have been abbreviated as initial, repeatable, defined, managed, and optimised. These levels have been selected because they (Saiedian and Kuzara, 1995):

- Reasonably represent historical phases of evolutionary improvement,

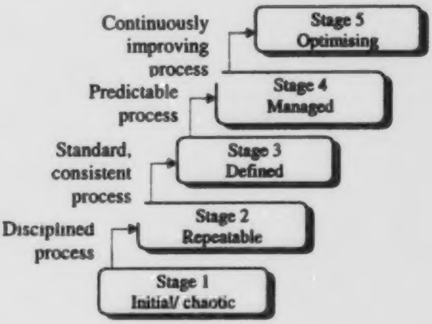

Fig. 1: CMM Levels

- Provide achievable improvement steps in reasonable sequence,
- Suggest interim improvement goals and progress measures, and
- Provide immediate improvement priorities once an organisation's status in this framework is known.

Generally, the levels are characterised and distinguished as:

1. *Initial*- While there are many degrees of management control, the first step is to roughly predict schedules and costs. This level has been described as "ad-hoc" or "chaotic". At this level the businesses produce products, however, the processes are not under systematic management control.
2. *Repeatable*- The organisation has achieved a stable process with a repeatable management control level, by initiating rigorous project management of commitments, costs, schedules and changes.
3. *Defined*- The organisation has defined the process as a basis for consistent implementation and better understanding. At this point, the risk of introducing advance technology is greatly reduced.
4. *Managed*- The organisation has initiated comprehensive process measurement and analysis. This is when the most significant quality improvements begin.
5. *Optimising*- The organisation now has a foundation for continuously improving and optimising the process.

Table 1: CMM's Key process areas

Level 5: Optimising	Defect prevention
	Technology change management
	Process change management
Level 4: Managed	Quantitative process management
	Software quality management
Level 3: Defined	Organisation process focus
	Organisation process definition
	Training programme
	Integrated software management
	Software product engineering
	Inter-group coordination
	Peer reviews
Level 2: Repeatable	Requirements management
	Software project planning
	Software project tracking
	Software sub-contract management
	Software quality assurance
	Software configuration management

2.2 Key process areas

Each CMM level except Level 1 includes key process areas (KPAs) that identify where an organisation must focus to improve processes (see Table 1). Because at Level 1 the organisation has not achieved systematic process improvement in any areas, there are no KPAs for this Level. When an organisation collectively performs the activities defined by KPAs, it can achieve goals considered important for enhancing process capability. All KPAs include both project and organisation responsibilities, but primarily the project is responsible for addressing many KPAs. The organisation is responsible for providing the resources and the necessary infrastructure.

3 Applicability to the construction industry

Many of the CMM concepts appear generic. At first glance it appears that if you replace the word "software" with "construction" in Table 1, the KPAs would remain meaningful. This raises the issue of the possibility of benefiting from the productivity improvements of CMM, in construction.

The above hypothesis was put to test in the SPICE project. The project conducted three studies to investigate. These are discussed below:

3.1 The questionnaire

As part of the initial SPICE research, a reduced and modified version of the CMM assessment questionnaire (Paulk 1993) was sent to industry professionals across a broad spectrum of disciplines (Finnemore 1998). The questionnaire was distributed to organisations within the industry (contractors, architects etc.) and also organisations not directly involved in the industry, such as clients and suppliers. The intention was to capture an internal and external perspective. The objectives of the questionnaire were to:

- Generate industry awareness
- Establish if the adapted KPAs were applicable to construction
- Identify additional KPAs
- Align research with the construction industry (terminology etc.)

At this stage the questionnaire was **not** attempting to establish industry maturity.

The questionnaire was developed by re-wording the descriptions and individual questions of the original CMM questionnaire (Pulk 1993) to reflect construction industry terminology as closely as possible. For example, 'requirements management' became 'brief / scope of work management'. The questionnaire was then issued to over 100 individuals of which 30 have replied to-date. The limited scope of the questionnaire and inexact target audience means that the collected data is unsuitable for any detailed analysis but nonetheless has returned some useful indications.

It was apparent from the responses that not only were the questions read but also understood.

- The key process areas were recognised and confirmed as relevant.
- The comments and suggestions made gave direction on future terminology.

3.2 The assessment case study

A small firm of architects participated in a case study of a process maturity assessment. The purpose of the case study was to examine the applicability of the CMM's process improvement concepts and assessment mechanism to the construction processes. A firm of IT management consultants conducted a short version of CMM assessment.

The general findings of this assessment that could be gleaned from the case study were as follows:

- Construction participants generally understood the issues addressed in the CMM questionnaire.
- The assessors (from the IT industry) could relate to, and interpret the pattern of the responses (in a construction company). The responses reflected some organisational characteristics, which are also encountered in software development organisations.
- Organisation culture and communications issues in construction are similar to those encountered in software development organisations.
- With one or two notable exceptions, process capability characteristics are broadly similar to that in the software industry.
- Systematic quality management, change management and other project control mechanisms would have similar benefits in the construction industry, to those anticipated in the software industry.

Some of the differences between the construction and software development industries, which were noted by the IT management consultants were that:

- In construction, professional qualifications, customs and working practices are better established.
- In construction industry standards and data are more readily available.

3.3 The experts' opinion workshop

A panel of experts was invited to review the findings of SPICE. The panel consisted of 24 senior industrialists and academics. The academics had construction expertise. The industrialist represented the contractors, sub-contractors, consultants, architects and facility management specialists. Around half the experts were industrialists. The findings can be summarised as follows:

- The panel generally was supportive of the process maturity approach and concepts. It embraced the definition of process maturity and found value in the framework.
- The major concern regarding the framework was its applicability to the construction supply chain. CMM applies to single organisations. In order to improve the product in the construction industry, the framework must address the project supply chain.

- The assessment mechanism appeared similar to existing quality assessments, with little differentiation. The cost of the process was seen to be too high for construction companies in general and construction SMEs in particular.

4 Summary

SPICE is a current research project that is attempting to tailor the successful Capability Maturity Model (CMM) from software industry to a construction industry specific model. The model will provide an evolutionary framework for business process improvement and also an assessment tool for organisational maturity.

An industry questionnaire, a case study, and a meeting of industry representatives have indicated that a construction industry CMM model and process improvement in general are feasible. On-going research will continue to develop this concept.

Some of the main findings to date have been:

- Organisation culture and communications issues in construction are similar to those encountered in software development organisations.
- Quality management, change management and other project control mechanisms would have similar benefits in the construction industry, to those anticipated in the software industry.

Some of the main differences between the software industry and construction are:

- In construction, professional qualifications, customs and working practices are better established, and also standards and data are more readily available.
- The cost of the process was seen to be too high for construction companies in general and construction SMEs in particular.
- There was concern about the single organisation focus of CMM, as opposed to the complex supply chain arrangements in construction projects.

Three studies (i.e. questionnaire, case study and expert opinion workshop) in this paper all indicate that there is value in attempting to tailor to the construction industry, and that the major process improvement concepts in CMM are applicable. However, the major issues are finding the right framework, which:

- appropriately addresses the supply chain;
- provides the appropriate tools for the different organisations within the supply chain, in terms of organisations size, financial status and business focus.

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272 MODEL BASED CONSTRUCTION PROCESS MANAGEMENT

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Abstract

The purpose of this research was to study how the data management of a ma contractor can be improved, in order to provide better client value and more co efficient production. The research focused on methods for reengineering t information management using product modelling as an enabling technology. T methods were tested in pilot tests in which the developed cost and val engineering prototype application was used.

This paper demonstrates an integration of design and production planning bas on the product model approach. The final outcome is that the main contractor c utilise information coming from designers as input in its own tendering and cc estimation applications.

The key methodology used for describing the information management proce throughout the building process life-cycle was IDEF0. The analysis of the curre process (as-is), in the form of an IDEF0 model, helped in identifying the ma problems of current practice. The target process (to-be) definition was based product model utilisation and takes into account the possibilities for proce reengineering supported by product data technology. One specific requireme was deemed important in view of the anticipated developments in the area of da exchange; the target system should be structured in such a way that it could easi be adapted to receive data according to the emerging Industry Foundation cla (IFC) core model schemas.

The overall result of the research reported in this paper is that the product moc approach can be used for a substantially reengineered information manageme process of a main contractor, especially in design and constructdesign/build ty contracts.

Keywords: Cost estimation, information technology, process model, buildi product model, reengineering, knowledge engineering

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1 Introduction

1.1 Need for reengineering the information management process

While other industries have been able to achieve very significant improvements in productivity and quality over the last few decades, the construction industry seems to have been at a standstill. The industry has not been able to combine high quality with productivity, customer satisfaction and flexibility. Competition remains mainly focused on lowest cost and offering capacity instead of quality, sustainability and customer-perceived value. The construction industry is, in particular, lagging far behind other industries in using modern technology as a major catalyst for improving its processes.

The information management methods used in current construction processes are inadequate. In particular, the traditionally separation of design and production causes problems in the form of duplication of work, inconsistent documentation, etc. According to a study carried out in the UK (Latham 1994), 30% of the total building costs should be saved when information problems such as repeated work, overlapping work, false information, redoing, etc., are solved. Improved data exchange and the overall managing of the information will be a key solution to this. These problems can not be solved by more advanced IT tools alone. Reengineering of the process itself is necessary (Betts 1997).

1.2 IT-tools that support reengineering

Early developments in construction computing provided support for activities where information was created. Good examples are the use of CAD-systems for drawing production and spreadsheets for cost calculations. During the last few years new emerging IT-technologies have increasingly been used to facilitate information management and transfer in the construction process. Computer networking, document management systems, the Internet, database technology and interoperability standards provide examples of such technologies. The potential of these for data sharing has, however, not been fully utilised in the construction industry, but has rather been used for exchanging traditional documents in a digital format.

One promising technology for data exchange and sharing, the commercial use of which is still in its infancy, but which has been the subject of quite intensive research during the last decade, is product data technology (for a recent overview, please see Eastman and Augenbroe 1998). In product models the information about a product (in our case a building) is stored as information objects in databases, according to data structures which have been standardised. In contrast to today's practice information is stored only once and the needed documentation is produced from the product model using applications. Many European research projects, such as CIMSteel (1998), ATLAS (Tolman *et al.* 1994) and COMBINE (Augenbroe 1994) have developed methods for product model based information exchange. The development of the fundamental standards needed for building product data exchange is currently going on both as formal standardisation through the ISO STEP committee (ISO 1993), and through active industry participation in the Industry Alliance for Interoperability (IAI 1997), which is developing object-oriented building descriptions, so-called IFCs.

1.3 Aim and objectives of the research

The overall aim of this research was to study how the data management of a general contractor, who mainly aims at working in design/build projects, can be improved, in order to provide better client value and more cost-efficient production. For the client the key issue lies in the information provided for decision support. For the contractor the major improvements can be foreseen in the tendering activities as well in cost and value engineering management.

In order to achieve such improvements the operational target was to be able to manage requirements information, design and production information in an integrated manner throughout the construction process. In essence, this meant that the research focused on methods for re-engineering the information management of the main contractor, using product modeling as major enabling technology.

1.4 The Case company: YIT Corporation

This kind of research proposed, which includes wide scale testing of changed business processes, can only be possible to carry out in close co-operation with industrial companies in order to follow the strategic business targets of the companies and to verify the results in real projects. The research was carried out as a case study inside Finland's largest contractor, YIT.

YIT's Division for Building Construction is the leading contractor for residential, office and industrial facilities in Finland, with residential buildings constituting 55 % of its total production. Over 60 % of the production is carried out in design/build projects.

YIT Building Construction has an internal R&D -department, which focuses on customer decision supporting systems, quality systems and business process reengineering supported by enabling IT-technology.

2 Problems of the current information management process

2.1 Analysis supported by process modelling

In this study the construction process used today by the case company was analysed throughout the whole life-cycle of the process. The focus was on the main contractor's viewpoint and on information and process management, in particular in design/build type projects. The analysis was carried out through interviews with experts in the company, through studies of existing project documentation and internal company guidelines as well as a study of the software tools currently used in the company. The analysis work was supported by formal IDEF0 modelling (Marca and McGowan 1987; Laitinen 1998).

2.2 Shortcomings in information exchange

According to the study, the main shortcomings of the information management methods used by the contractor, either in "bid and construct" or "design/build" type projects, may be summarised in two main points:

- From the customer's point of view, the contractor cannot provide sufficient decision support throughout the process.

- From the contractor's own point of view; poor information and data management, especially concerning the integration and sharing of data.

  Some major current problems are:

  - There are no tools to create enough information in the briefing phase to adequately support decision making and no capability to use information from reference projects as cases effectively.
  - Hand over and as-built information for users and owners is poor.

- The information exchange between designers and between designers and suppliers is usually limited to paper drawings and is thus slow.
- The information flow between designer and contractor is based on drawings. Contractors are not able to efficiently use design information as basic data in their applications.
- The contractor's systems do not work together (no internal integration). Information which has been input into one application cannot be transferred to other applications.
- In general, the feedback mechanism is poor. There is no upstream feedback from the use phase to briefing at the start of later construction projects. A consequence of this is that estimations for life-cycle economy and other assessments are based on very limited knowledge.

3 The enabling technology – product modelling

3.1 Fundamental elements of product data exchange

Product data technology can be defined as a set of IT methods, tools and standards for the development and implementation of applications for the management, exchange and sharing of product data. In product data exchange shared data is stored only once, in a product model from which the different participants in a construction project can retrieve data and to which they can add data. This is in contrast to the current document-centred approach in which the same information is often independently stored in several documents, making it difficult to keep track of changes. Figure 1 presents the conventional versus product model approaches.

3.2 The STEP and IAI standardisation efforts

The central effort in the development of product data technology has been the international standardisation work in ISO TC184/SC4 Industrial Data committee. The main result so far has been the so-called STEP-standard, officially known as ISO 10303 *Product data representation and exchange standard*. Details are found in Laitinen (1998).

The International Alliance for Interoperability (IAI) is a recently founded industry effort whose goal is to develop product data models for sharing information between software tools which are utilised throughout the Building Industry (IAI 1998). These models (or rather the class definitions that form them) are called Industry Foundation Classes (IFC). The IAI is a group of over 600 AEC related companies and organisations located throughout the world.

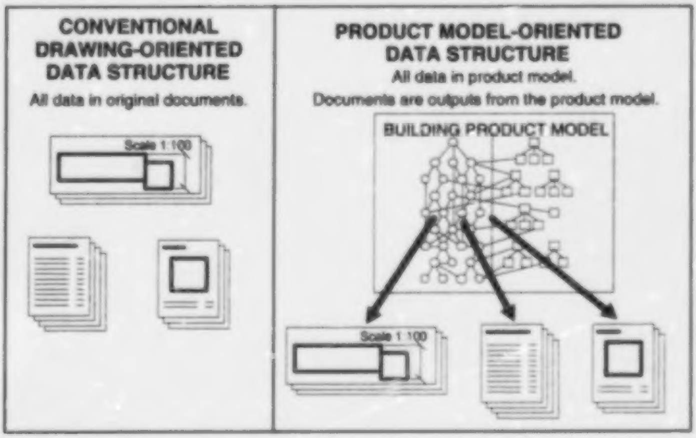
CONVENTIONAL DRAWING-ORIENTED DATA STRUCTURE
All data in original documents.
Scale 1:100
PRODUCT MODEL-ORIENTED DATA STRUCTURE
All data in product model.
Documents are outputs from the product model.
BUILDING PRODUCT MODEL
Scale 1:100

Fig. 1: Document-oriented approach versus proposed product model (Björk 1995)

After having been started as a relatively independent effort, the IAI has increasingly taken into use techniques that have earlier been developed within STEP. Thus the EXPRESS language and the STEP physical file format are used and there is quite a lot of reuse of models or parts of models. Discussions are also going on to reach an agreement ensuring that the duplication of effort is minimised and that the resulting standards – the STEP application protocols and the core model – and de-facto standards (IFCs) as far as possible are compatible or even the same.

3.3 Integrating product model data with process information

Since around 1991, a number of researchers have started to look at the problem of how to provide an infrastructure for integrating the possible future product models produced by designers with the software applications used by contractors for cost estimating and scheduling (Froese 1992), (Luiten *et al*. 1993), (Luiten 1994), (Fischer and Aalami 1995). The proposed solution has been to define conceptual schemas defining the relationships between building elements with the activities that produce them and the resources used. The term "construction project model" has been used for such schemas.

Currently there are a number of standardisation efforts where generic construction project models have a significant role to play. In a recent ISO classification report (ISO 1997) some conceptual schemas on a high level are also included. In the IAI development work the IFC core model already contains some generic classes related to construction activities. The project management domain group within the IAI has also started to develop more detailed models (Froese 1998).

4 The target information management process

4.1 Requirements and aims for the target process

The new proposed information management approach is based on the application of product model technology, especially for the purposes of cost and value engineering. The utilisation of the product model covers all phases of the building project. The aim is to integrate the information of the designers and the contractor in such a way that the data from the design work can be used as source data directly, without manual input, for calculating the tender as well as for production planning (i.e. the information produced by the designers is integrated with the contractor's know-how).

There are three main requirements for the target process:

- Provide more information and alternative solutions to the customer and the other participants within the building construction process.
- Provide more accurate information in earlier phases of the process.
- Utilise information created beforehand (cases) and classified technical solutions embodying the contractor's knowledge.

The target process is from a decision support point of view illustrated by Figure 2, which is based on the approach that key activities are shifting to earlier phases.

The traditional design process is divided into different phases of design, starting with briefing and ending with the production of working drawings. In integrated, model-based design, there is no such clear distinction between the phases: instead, the phases of the design process constantly interact and complement each other. The data content of the artefact being designed becomes more detailed and data accumulates continuously as the process advances. All new data are produced once only and are used as input data for the next 'phase'.

4.2 The high-level view of the target process

The top level of the IDEF0 model for the target construction process includes only one activity, *design and construct building* which defines the inputs and outputs of the entire building project. The second level (A0), shown in Figure 3, is a wider view where the model based construction process approach is described from the customer's, contractor's and building user's point of view.

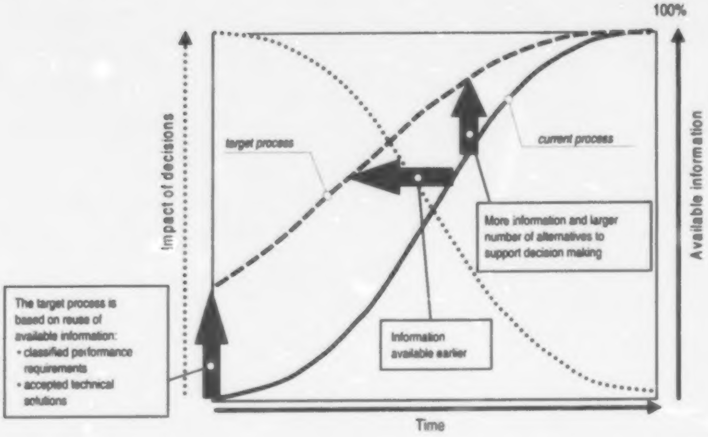

Fig. 2: Decision making versus available information (Adapted from Fisher *et al.* 1993)

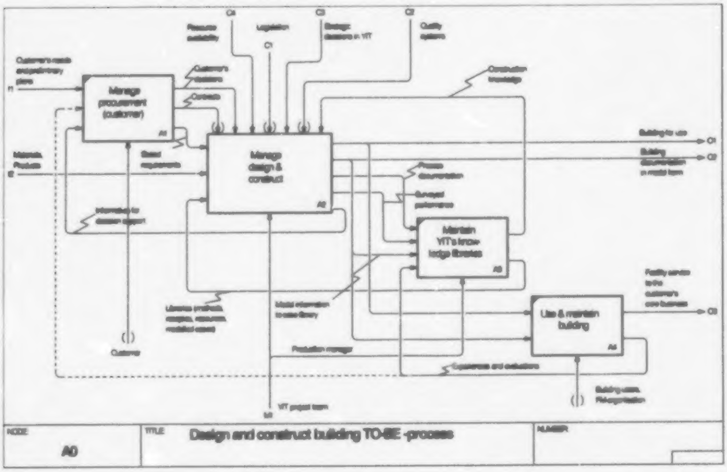
C4
Resource availability
Legislation
C1
C3
Strategic decisions in VTT
C2
Quality systems
Customer's needs and preliminary plans
I1
Manage procurement (customer)
A1
Customer's decisions
Contracts
Construction knowledge
Materials, Products
I2
Stated requirements
Manage design & construct
A2
Building for use
O1
Building documentation in model form
O2
Process documentation
Surveyed performance
Information for decision support
Maintain VTT's know-ledge libraries
A3
Facility services to the customer's core business
O3
Libraries (methods, designs, resources, modelled cases)
Model information to case library
Use & maintain building
A4
Customer
Production manager
Experiences and evaluations
Building users, FM-organisation
VTT project team
M1
NODE
A0
TITLE
Design and construct building TO-BE -process
NUMBER

Fig. 3: Design and construct, to-be (A0)

The activity *customer's procurement process* (A1) is, compared to the current situation, based on more accurate information for decision support coming from the contractor's activity *Manage design and construction* (A2).

The contractor's activities, M*anage design & construction* (A2) *and Maintain YIT's knowledge libraries* (A3), are supporting each other better than in the as-is process. The main inputs for the knowledge libraries are model information to case library, process documentation and surveyed performance. The libraries are organised according to the building type (e.g. apartment buildings, office buildings) so they can be used as cases and as construction knowledge to control future projects. There are approved YIT-solutions for systems, production methods and structural details. The evaluation of the production performance improves the accuracy and reliability of recepies and methods which are inputs (libraries) for design and construction management and thus forms the basis for constant/standard work unit scheduling. The feedback from the activity *Use and maintain building* (A4) improves the life-cycle performance knowledge in the YIT-libraries.

4.3 Manage design and construct

The activity *manage design and construct* (A2) is shown in Figure 4.

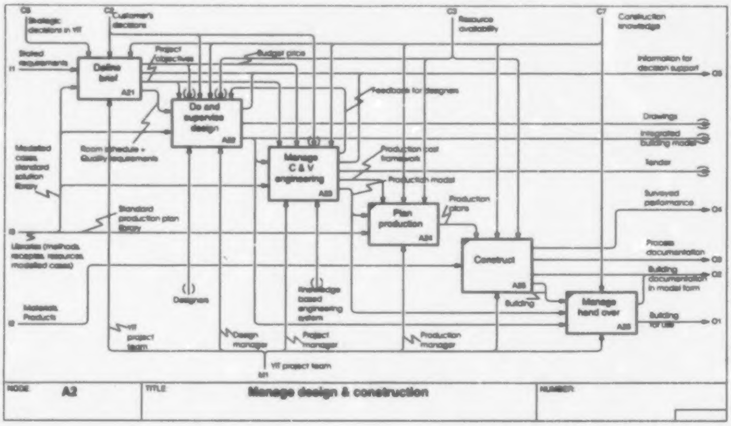

Fig. 4: Manage design and construct (A2)

The briefing phase, *Define brief* (A21), results in a space utilisation plan together with quality requirements, the expression of which in model-based design is a preliminary architect's aspect model including quality specifications on a per space basis. This serves as the basic data for the integrated building product model to be made in the design phase.

In *Do and supervise design* (A22), the designers each make their own part of the product model, which the contractor evaluates and gives feedback on. The integrated model based design process starts out with the architect's draft aspect model, which models the building's shape, spaces, structural allocations (enclosing walls, ceiling/roof and floor) and the quality standard. After that, the structural engineer models the structures on the basis of the architect's allocations, possibly suggesting necessary modifications to the architect. Similarly, the installation designer models the technical conduits and furnishings according to the architect's space model.

The building product model grows and becomes more detailed throughout the design phase. At the *Manage C&V engineering* (A23) stage, the model contains all the design data for the building and the basics for design solutions as well as the planned production methods. After the integrated design phase, the production model data are used in the production planning and construction phases.

In the *Production planning* (A24) phase, data is used for planning time schedules, purchases and logistics. In this phase especially the knowledge of quantity and location data of building elements is used. Data specified once need not be measured again as they can be downloaded from the production model in the desired form, for example as partial outputs of wall panels or building frame structures.

The feedback from the phases *Construct* (A25) and *Manage hand over* (A26), serves as a guiding factor for the early activities in upcoming projects. These are modelled as outputs of the *Manage design & construction* activities, and are used as input in the *Maintain YIT's knowledge bases* activity. Experience data is also stored in the case library of modelled projects in YIT's knowledge bases. Final output is not only the building ready for use but also an as-built model for owners and occupants.

4.4 Manage cost and value engineering

The design solution data is analysed and evaluated during *Manage C&V engineering* (A23), Figure 5. This phase covers the composition of the production model using the contractor's knowledge-based application. Proposals for changes to guide design work are produced as a result of the process, e.g. changes due to analysis of alternative solutions like production methods etc. The practical implementation of the process procedures (mechanism) necessitate the use of knowledge based engineering techniques (KBE). Data on production engineering are transferred to other partners in the form of partial models from the production model as necessary, especially when alternatives are being investigated.

The *Analyse the design* (A231) activity involves analysing the scope, efficiency, form and functionality of the design solution, partly based on statistical methods and comparative data from other, similar projects. Co-operation with the user would be highly advisable for the assessment of the building's functionality.

In the *Compose production model* (A232), the contractor's know-how is added to the building product model. Aspect product models transferred by the neutral model are put together into the building's product model and then composed into the contractor's production model. Default production methods for the production qualities of the product model's components are accessed from the 'case' library according to the project type. This covers all production knowledge, methods, recipes, resources, materials and equipment needed to accomplish the building.

Basic data for the time scheduling application is generated using the production model, which is used to produce a provisional schedule for the project. The activity *Make schedule and plan construction* (A233), includes both the making of a schedule for the project and the analysis of the construction plan and especially its constructability. The schedule guides and to some extent restricts alternative forms of product planning, which helps to control costs. This activity seeks alternative solutions for production.

In *Study alternatives and make proposals for modification* (A234), the economy of the project is determined. *The Make alternative calculations* (A235), covers examining the cost impact of the alternative solutions put forward to designers, for instance concerning the most economical space solution, the most economical alternative structure in production terms or the cost impact of the client's requests for changes.

The determination of comparative calculations, like those of the overall costs, should be based on the contractor's own cost database, methods and recipes as well as the associated real-time input prices, so that costs can be assessed with precision even at an early phase.

The assessment of life-cycle economy generates a calculation of the costs of using, maintaining and repairing the building throughout its service life. The assessment of these costs is based on estimated repair and maintenance at calculated intervals according to the usage of the spaces.

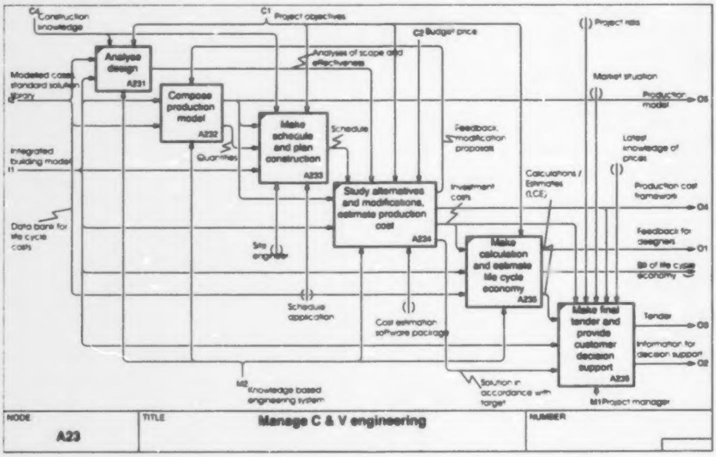
C4 Construction knowledge
C1 Project objectives
C2 Budget price
Project risks
Analyse design
A231
Analyses of scope and effectiveness
Modelled cost standard solution library
Compose production model
A232
Market situation
Production model
O5
Make schedule and plan construction
A233
Schedule
Feedback, modification proposals
Latest knowledge of prices
Integrated building model
I1
Quantities
Calculations / Estimates (LCE)
Study alternatives and modifications, estimate production cost
A234
Investment costs
Production cost framework
O4
Data bank for life cycle costs
Site engineer
Make calculation and estimate life cycle economy
A235
Feedback for designers
O1
Bill of life cycle economy
Schedule application
Cost estimation software package
Make final tender and provide customer decision support
A236
Tender
O3
Information for decision support
O2
M2 Knowledge based engineering system
Solution in accordance with target
M1 Project manager
NODE
A23
TITLE
Manage C & V engineering
NUMBER

Fig. 5: Manage cost and value engineering, to-be (A23)

The final tender and documentation will be produced in *Make final tender for the customer and create decision support* (A236). This information forms the decision base of the analysed alternatives, their impacts and reliable calculations.

Due to the utilisation of the production model it is easy and quick to make alternative calculations in order to evaluate their impact on the costs and production. The life-cycle economy evaluations in terms of energy and cost are possible to do using the same production model and data bank of life-cycle costs.

A comprehensive presentation of the target IDEF0 model, as well as the current as-is process model, can be found in (Laitinen 1998).

5 Technical solution

5.1 Choice of basic platform

For the prototype work the Design++ system was chosen as a basic software platform. Design++ is a knowledge-based engineering (KBE) tool for engineering and design automation, which supports both engineering decision-making and drafting tasks (Katajamäki 1991). The underlying data model of Design ++ is a frame-based representation, which has been quite a popular representation mechanism used in knowledge-based system. In the earlier versions the core of Design++ was based on the KEE environment, which has originally been programmed in the LISP language, but later versions are programmed in C and C++.

In addition to the knowledge-based core Design++ also incorporates a commercial CAD-system and a relational data base system. This is because the CAD-system has a good user interface and good facilities for manipulating the geometrical aspects of a model, and because a data base system is good for storing and searching in large repositories of homogeneous data, for instance about components.

The parts and assemblies used in a model are defined as classes in libraries. A class must exist in a library before creating an object (instance) of it. Once a component (object, instance) is created in a model it may have local individual attribute values that can be modified.

The attributes of classes are defined interactively using tools provided with the user interface. Rules that are attached to class attributes can be used to capture the expertise used in the design process.

The library classes are defined in a hierarchy, which is represented graphically by a tree. A class can be defined broadly and then refined into successively finer subclasses. Each subclass incorporates, or inherits, all of the properties of its superclasses and adds its own unique properties. A subclass may inherit properties from more than one superclass (multiple inheritance).

5.2 The apartment building product model

The data exchange paradigm of the prototype system (Serén *et al.* 1996) complies in general well with the principle of a core model supported by aspect models, which was presented in section 3. The ***apartment building product model*** is the union of all the model data created by any of the project participants and which describes the apartment building as a product.

The ***apartment building core model (ABCM)*** is that subset of the apartment building product model in which more than one participant has an interest and may need to access. An example of data structures included in the ABCM is shown in Figure 6.

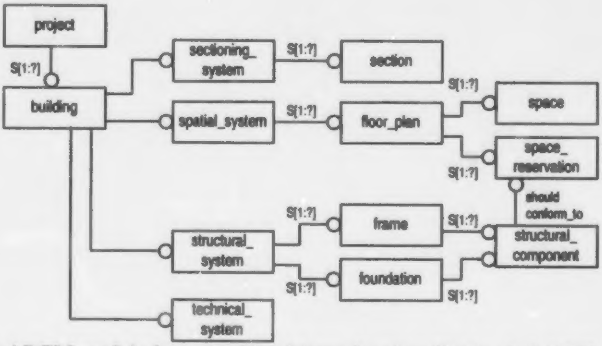

Fig. 6: ABCM model: decomposition hierarchy view (Serén *et al.* 1996)

The ***architect's aspect model*** contains all the information in which the architect is interested. Part of this data is also important for the other participants (for instance the placement of walls) and belongs consequently to the ABCM. This part can also be information created by other parties which has relevance for the architect. Other data, such as the colour of walls, is not relevant for any of the other participants and belongs to that part of the architect's aspect model which doesn't intersect with the ABCM.

The ***structural engineer's aspect model***, the ***building services engineer's aspect model*** and the ***contractor's aspect model*** are defined in a similar way.

The ***contractor's production model*** is the union of the contractor's aspect model, which is a subset of the overall building product model, and the relevant information on recipes and methods (here been called the production knowledge) needed to produce the building components.

The management of the logical contents of the shared information relies on the knowledge-based tool used by all the partners, and some solutions are based on the specific features of this tool. The product models of each partner are structured according to the common model (ABCM) implemented as standardised class libraries shared by all partners. The partners are able to specialise these classes according to their own needs in their applications which deal with the information belonging to their aspect models. In addition, a basic reference product composition structure file is used.

5.3 Data exchange format

Using this meta-model meant that mapping software had to be developed from the ABCM model to the OOCAD meta-model, and vice versa. Most of the information contained in the ABCM can be transferred; design rules and knowledge can not be transferred as such.

Figure 7 is an overview of the mappings included in the data exchange (from a participant's aspect model to the core model ABCM and from the core model to the data exchange model)

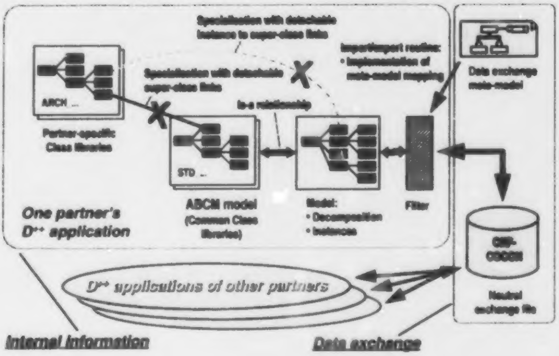
Specialisation with detachable instance to super-class links
Import/export routine:
• Implementation of meta-model mapping
Data exchange meta-model
Specialisation with detachable super-class links
ARCH ...
Is-a relationship
Partner-specific Class libraries
STD ...
ABCM model (Common Class libraries)
Model:
• Decomposition
• Instances
Filter
One partner's D⁺⁺ application
Neutral exchange file
D⁺⁺ applications of other partners
Internal information
Data exchange

Fig. 7: Overview of the different mappings

5.4 Network solution for the data exchange

An Internet-based network solution was chosen as the basic infrastructure for the pilot integration environment. The pilot project was one of the first attempts in Finland to use the Internet for data exchange in real-life building projects.

The physical network connections and system administration are based on a centralised project server, to which the partners have access via Internet connection services. The individual aspect models of each partner are used locally and only the common class libraries belong to the ABCM and the data exchange files are distributed via the server. Typically the partners use modem-based dial-up connections. The project server is set up with home directories for each partner. Each partner has full read/write access rights to his own directory and read-only access to the other directories. The directory system is password-protected.

5.5 The Cost and value engineering system, COVE

YIT's production model is created by the so-called "COst and Value Engineering" system, for which the abbreviation COVE will be used in the following. This application is based on the corporation's knowledge of its own production: structural solutions, production methods and recipes and input price lists of resources and equipment.

COVE's own application-specific libraries include the attributes required to analyse costs and scope data. Eventually life-cycle economy and environment will be added when that kind of knowledge of building materials and products becomes available. The COVE libraries are linked with superclass link to the standard ABCM libraries shared by all participants.

The overall structure of the COVE model complies with the product structure of the ABCM core-model. In the class specification, an apartment building and the structures and spaces used in it have for the time being been taken as the reference point.

In COVE a building is decomposed into a spatial system, a structural system and an installation system (building services) corresponding to the architect's aspect model, the structural engineer's aspect model and building services designer's aspect model, respectively.

For each product structure class, interface functions have been developed for the creation of components and for specifying and checking attributes through interface windows. The options in the interface windows are the values of the production model components' production attributes, i.e. production knowledge. The production model components generated in the case of integrated design are in a similar way given their attribute values.

5.6 The creation of the production model from the designers' product model

In the case where the designers are already using product-modelling tools, which is not the current practice, the COVE system can use designer's output data as input data directly. As described above, the ABCM core-model sections modelled by the various designers are transferred into the COVE application by OXF data communications using mapping software.

After the product model has been created or imported it is processed by adding to it production know-how (to the building elements), either in the form of default values or by the interactive (through the user interface) selection of methods individually or for the various types of building elements. After the inspection of the product model and the addition of production know-how, the result is a production model that will serve as input data for production requirements. The production model is created quickly using the information in the ABCM core-model and with little extra work for the contractor. The COVE model can also be created using only a part of the ABCM core-model. For example, a structural model made by a structural engineer may be used, augmented with COVE for the spaces. The COVE model of a typical apartment building is illustrated in Figure 8.

5.7 The creation of the production model from paper drawings or CAD-files

The structure of COVE is such that the creation of the production model is also possible without the imported product model data. In this case the model is built interactively by the cost analyst through interpretation of paper, or CAD-drawings (in the format of AutoCad dwg files) emanating from the designers. In this case the creation of the product model and the production model are integrated and performed simultaneously.

The modelling of the building may be performed with the help of tools built into the interface application, to facilitate fast and simple routines for drawing components and attribute specification. The production model is created solely through the interface functions; i.e. the model and its components are built up as the user 'draws' the building and its structural elements.

The dependencies between components are clearly defined when they derive from the product structure hierarchy. This is a 'part-of' relationship between components. Some 'connected-to' relationships are also used in the COVE model, the expression of which is less distinct. Such a dependency may occur, for example, between spaces and the walls (or similar structures) surrounding it when space components are created.

The object-oriented nature of the COVE model makes it easier to create and process a model. When constructing the model, it is possible to use the components' copying attribute in such a way that, for example, the load bearing structures of a high-rise apartment building are modelled in the lowest storey and copied 'upwards' on other, similar storeys. Similarly, the apartments are modelled on the bottom storey and copied upwards. Also, when making changes to the attributes of the production model's components, they propagate to all similar cases in the model in question.

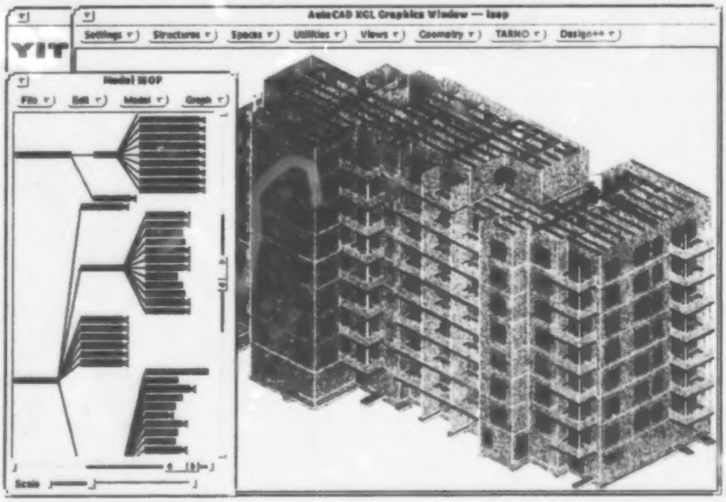

Fig. 8: User interface and the model with hierarchy in the COVE application

Determining the geometry of a component takes most time when it is derived from an architect's drawings on paper. In this case it is necessary to measure the geometrical information of the building elements with a ruler and enter them in numerical form while creating the components.

Modelling is simplified if the architectural plans are available as CAD-files. In this instance an architecture layer is formulated from each storey, and this is used as the base image in AutoCad. In the modelling of the building the architectural layer is used to 'draw' the geometry of the components, a process that resembles digitising.

6 Discussion

6.1 Comparison of the results with other published research

Although the results of the analysis of the current process, presented in section 2, are based on an analysis carried out inside one case company, they are very much in line with similar results reported by other researchers (Aalami and Fischer 1998; Froese 1992). The main conclusions are that the current document-based data exchange offers insufficient support for the customer's decision making in early stages and for reuse of already created data later on in the project management process.

Some visions on how to use product modelling as an enabling technology for reengineering the processes of individual construction companies have been published (Yamazaki 1990). The author isn't aware of other examples of re-engineered construction company process models, such as the one developed in this research and presented in section 4, which would have been reported in the research literature. Although there are a number of on-going R&D projects which include such modelling in their scope (i.e. the European CONCUR project (Storer and Los 1997). There are two likely reasons for this; firstly that formalised techniques like IDEF0 are seldom used by companies in the construction industry, secondly that companies are unlikely to publish the results of such modelling efforts.

The architecture of the prototype supporting the re-engineered process (Section 5), based on a core model supported by aspect models and a production model, can be compared to models defined by other researchers. In the PreFacto system (Jägbeck 1996) the generic product data model holds a core of information needed for managing a construction project. Also in PreFacto the product description is based on a neutral core model solution influenced by STEP. The information is imported from design documents and is used as input for creating PreFacto's own aspect model (a Production Management Model), which is quite similar in scope to the contractor's production model of this study.

The minimal NICC (Neutral Intelligent CAD Communication) conceptual schema (Tarandi 1998) specifies the use of concepts for the exchange of computer interpretable information relating to all parts of buildings. NICC contains building object shape and type, connectivities, assemblies and graphical representation. The production aspect is not as pronounced in NICC as in the COVE-application, which includes production knowledge in terms of methods and recipes.

Luiten and Fisher have tested the usefulness of a conceptual project model and system architecture as information models for integrated construction management in the prototype system called SPACECAKE (Luiten and Fischer 1995). The conceptual project model was built up of project classes and their attributes and relationships. The main finding was the need for the development of computer interpretable representations of construction knowledge, which complies well with the direction of this study.

6.2 Experiences of the YIT staff

The following discussion is based on interviews made with YIT staff after the pilot projects and after some other test projects, and with staff from design offices during and after the pilot projects.

The examination of the extent of the building and of the various characteristic figures is based on the user's conclusions drawn from the COVE calculations. The way these characteristic figures are used has so far depended entirely on the user's skills and experience. In addition to the easy calculation of these traditional characteristic figures, COVE enables the calculation of many characteristic figures, which can be derived from the shape, and the quantities of various construction elements described in the model. So far there is no experiential basis for the comparison of these. As the number of models rises, and as systematically compiled statistical materials accumulate, the possibility arises of analysing the data on the basis of comparative statistics, which will yield information on the importance of these characteristic figures to design management.

The examination of the functionality of a design solution is still performed through a graphical user interface. In other words, the user examines the designs with AutoCad images and draws conclusions on the basis of his own knowledge. It was found that these requirements are difficult to describe as design rules for the system (Design ++).

A cost estimation produced with the COVE model currently covers about 60% of a full cost estimation. At present, the information generated by the production model can be used to determine the costs of spaces and structures, but the costs of technical systems, foundation works and site engineering must for the moment be determined separately for each project by traditional methods. Enhancements to the system are essential so that an all-inclusive cost estimation can be obtained.

It is possible to carry out comparative estimates by generating a transfer file from a limited set of components, e.g. facade elements or the building frame. In the initial phase of modelling it is possible to estimate the design by determining a cost estimation for the loadbearing structure alone. The quantity of the loadbearing frame and its cost are appropriate points of comparison also for assessing the scope of design. This feature was found very useful by the staff involved.

The required design data can be taken from the production model by inspecting the model from various perspectives, viewing only the needed components and attributes in isolation. This open product structure was found very useful in particular to procurement operations, in which the modules required by the building component trade can be freely demarcated and assembled together. Precise data on quantities and designs can be appended to tenders, so the supplier's quantity estimation is left out and the risks inherent in the supplier's tender are reduced as the appended material becomes more accurate.

As a conclusion of the experiences so far the interviews indicated that the achieved accuracy is acceptable and the savings in time are about 80 %. Also most mechanical and human errors are avoided and in addition it is always possible to check the model using visual Auto-Cad images. Alternative design and production solutions are relatively easy to create and quick to evaluate.

The most probable way in which the COVE application will be used in the near future is for modelling production models by the contractor's design management and estimation staff. Using AutoCad files as a basis for modelling is, for the time being, a convenient modelling method. Modelling on the basis of AutoCad image files was in the pilots found to be considerably faster than working with drawings on the paper. The time taken to precise modelling from paper drawings can be estimated as two to three times the time taken to model with AutoCad files (comparisons made in typical housing projects). However, the most important achievement according to the production planners is that now the information is in usable form for other activities (production planning, scheduling etc.) in later phases.

In summary the proposed main contribution of this research is that the product model approach can be used as the technical means for a substantially reengineered information management process of a main contractor. Although the testing is not complete, it goes a longer way into full-scale testing in an industrial setting than most of the reported building product model research. This type of applied research is very much needed to provide the "proof-of-concept" of the utilisation of product models within the construction industry, which is needed to convince company managers to go ahead and invest in reengineering the way their companies work.

7 Acknowledgements

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273 SYDOX/MATCOMP/XI: AN INFORMATION SYSTEM ADAPTED TO THE NEEDS OF CONSTRUCTION ACTORS

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Abstract

This paper presents the SYDOX/MATCOMP/Xi French project, whose goal is to provide the construction actors with an IT-based, on-line aid for component specification and selection at different levels of the construction life cycle. We will describe the main features of the information systems (IS), then specific aspects addressed by the project. SYDOX is aimed at defining and demonstrating a prototype to access information about MATerials and COMPonents used in construction, implemented on a WWW server and focused on a restricted sub-part of construction products. We will present the work done: methodology for data structuring, structure of the IS, database structuring, user interface, use of scenarios (enabling a selection and an adaptation of the information retrieved, on the basis of a set of criteria commonly used by professionals), hypertext links towards a taxonomic structuring of the information, application to window and floor, and some perspectives for the IS.

Keywords: building and construction, complex information, interactive information system, product and component databases, scenarios, WWW

1 Introduction

Construction activities (CONST) have been and are still basic contributions to our societies. Their wide scope and diversity are such that even systemic analysis does not help so far to handle their complexity with success.

A general system SYDOX, designed to deal with Complex Data and Information (DOX), is defined to facilitate and enhance communication between CONST experts, designers, manufacturers and end users. We combine two strategies to generate an optimised representation of the MATerials and COMPonents (MATCOMP) information and its attributes, both for storage

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(archiving) and intelligent access. The first one is a bottom up creation of MATCOMP data and information representation carried out to produce a practical CONST ontology and thesaurus recognised by all experts in the field. To downsize our work, we have limited the project through the choice of few CONST components, notably the « window component ». In the second strategy, we use a top down holistic mechanism, using specific scenarios through which we identify the part played by some CONST data at different levels and time locations of the CONST cycle. As we foresee to exchange and use *« external data and information »*, we have to stress the importance of standardising materials, products and processes data in our evaluation: special attention is paid to standardisation work undertaken in the domain of the *Industrial Data* (ISO TC 184 International Committee) (SC4 1998), leading to the STEP (ISO 10303 - Industrial automation systems and integration - Product data representation and exchange) (Nell 1998), P-LIB (ISO 13584-1 1995), MANDATE (ISO 15531-1 1997) standards, and *Business data* (Electronic Data Interchange (EDIBUILD 1998), but also to other kinds of documents, such as technical agreements and regulations.

The initial objective of improving communications between experts and companies of industrial CONST components proved to be a powerful approach to the sector, leading for the future, since their participation increases in modern building concepts.

2 The SYDOX/MATCOMP/Xi project

The analysis will be done through three axes, which are:

1. *a database approach*: an information system (IS) relies on a database structuring a collection of basic information needed by the system;
2. *a query approach*: to help formalising interrogations on the databases;
3. *a communication approach*: to define the whole set of communication procedures needed by the important heterogeneity of the storage/retrieval facilities, the communication protocols and the geographical location of computers.

2.1 General context of the proposal

Information systems are more and more needed by industrial companies for acquiring, structuring, and exchanging complex technical data they have to handle during the production process. Nevertheless, a second complexity axis must be added to the intrinsic complexity of the data, coming from the relational structuring of the data, necessary to enable a selection of competitive solutions able to answer given specifications.

This information system is mainly aimed at small and medium enterprises (SMEs), since they often have to face situations for which they do not have either the necessary skill or the tools enabling a permanent follow-up of the normative texts, or a continuous updating of the technical information needed by the projects they work on.

Fundamentally, this need is common to numerous industrial sectors. The methodology carried out will thus have to be applicable to different industrial sectors, with possible consequences on the level of complexity of the IS. A selection will probably have to be made between the complexity related to the degrees of freedom in the choice of candidate solutions and the technological level of the sector: high level technology and low degree of freedom or low level technology and high degree of freedom. The construction industry is characterised by:

- an *increasing complexity* with acceleration of the relations among the partners;
- an *increasing diversity* of the information and data handled, mainly due to the development of new representation structures (message standards such as EDIFACT messages, product or production management data standards: STEP, MANDATE and P-LIB);
- the *development of new software tools* able to deal with more and more important amounts and diversity of information.

2.2 Objectives of the project

SYDOX (« *Système de données complexes* » - complex data management system) defines an « intelligent » software system built on an integrated knowledge based approach. Its use in the domain of (construction) products and materials (SYDOX/MATCOMP) must provide the user with key-information, including innovative materials and/or use. The project can be viewed at several levels:

- SYDOX: software system enabling access to complex documents;
- MATCOMP: applied to the domain of materials and components;
- Xi: application to a specific sector: here: construction sector.

The aim of the project is the development of an « *information access* point », as an Internet WWW server enabling:

- a *dissemination of basic knowledge* essential for industrial companies which have to deal with the organisation and processing of their internal data, the use of data coming from clients, sub-contractors, professional associations;
- *updating and dissemination of information* related to the status of new standards and rules (decisions or discussions able to generate subsequent modifications);
- *development of relations between « providers » and « users »* of technologies and tools for complex technical data structuring and processing;
- *training* by means of interactive examples of the realisation of products using entity-relationship or object oriented modelling: industrial subsets or components.

In order to carry out an interactive information system, as quickly as possible, but also to show the feasibility of the basic concepts of the methodology, we proposed to limit the application field of the prototype to materials and industrial subsets used in the construction sector, only focusing on upstream production processes. We think that it is in this sector that companies (mainly SMEs) have to face the most important needs in terms of data structuring systems.

The objective of the project is to develop both a learning (base of information) and a know-how (base of methods) allowing industrials to structure their data related to materials/components according to their needs, in France and in Europe. In this project, we will analyse the methodology leading to the elaboration of the information and communication system. The result of this work will consist in the elaboration of a software tool prototype aimed at providing an information simple, tailored to the needs of the user and to the kind of question he may ask. This software can also be used as a training tool to learn how to use these new *Information Technologies*.

2.3 Structure of the project and partnership

2.3.1 Organisation of the project

To fulfil its role, the project has been organised through four tasks:

- **Data identification and structuring: state of the art:** to make an inventory of the existing data bases and information sources. This work relies on the good knowledge of the construction domain provided by the Technical Centres.
- **Identification of methods and tools necessary for data representation and structuring:** to identify, when they exist, the corresponding software tools. One of its functions is also be to help SMEs to follow the evolution of new electronic communication means.
- **Formal specifications of the information system:** main result of the project, providing a generic way for structuring the information. The potential users of the system will appear through scenarios, defined as sets of typical requests corresponding to the type of information generally asked for by these users.
- **Software prototype of the information system:** to build on an interactive software system, running in a client/server mode, with several input levels, enabling a use by several types of users. Its aim is to enable a short term validation of concepts defined by the project.

2.3.2 Partnership of the project

The current partners in the project include:

- **CODATA France:** scientific co-ordination (The SYDOX software is a development of SYCOGMA SA)
- **University of Savoie/ESIGEC/LGCH** (« *Laboratoire Génie Civil et Habitat* »)
- **Technical Research Centres:** CSTB (« *Centre Scientifique et Technique du Bâtiment* »), CTBA (« *Centre Technique du Bois et de l'Ameublement* »), CTICM (« *Centre Technique Industriel de la Construction Métallique* »).

2.4 State-of-the-art of the information handled in the construction sector

The starting point of the elaboration of an information system can be found in the capacity to identify, to interface, when it is possible, existing document repositories or product databases, whatever their structuring and location.

This project started with an analysis of the data intervening during the production process of a building, made in several ways:

- *identification of the needs of information* in the building sector, through the results provided by a previous sociological study, whose aim was to analyse the ways used by professionals of the sector to access the information they need;
- *identification of the professional stakes* of information related to products, materials and components.
- *usual practices in terms of research of information* related to products and materials, generally combination of different sources resulting from a permanent follow-up, or practical information related to specific points, but also specific needs of information to take decisions.
- *legal aspects of the information*: mentioned in multiple rules, codes of practice or other legal documents whose application is mandatory.

In a second stage, we tried to locate the data related to materials and components within the overall building project. We also explored several ways of classifying information, and meta-data.

The inventory of the sources of information has been done through the research of a possible « categorisation » by means of a table whose lines and columns represent :

- **columns**: possible « approaches » of the construction, in terms of life cycle stage, features of the construction, leading to the following headings: *constitutive elements, general features, achievement, regulation, environment, certification, safety, logistics*;
- **lines**: « themes » proposed for the information sources, based on a functional approach of the building. They have then been developed further to increase the relationship between the theme of a source and the headings of the columns.

This questionnaire has then been sent to the different Technical Research Centres partners of the project, to be completed with the available information. The answers received mainly apply to wood, and all products based on wood, concrete and derived products, regulation about the products, classifications, nomenclatures and steel profiles. An in-depth analysis of the answers highlighted several common characteristics:

- the *important number and diversity* of information sources;
- generally, these *information sources are rarely computerised*: the main part of the information is essentially accessible through paper documents: this was the most surprising feature discovered through this project;
- however, the *current situation is evolving*: development of computerised

catalogues, CD-ROM, use of the Internet/WWW capabilities;

- the *big heterogeneity of the information sources*: with important lack of consistency among the information contained.

3 The SYDOX/MATCOMP/Xi Information system

We will present the information system developed within the framework of the project: presentation of the methodology used for data structuring, then description of the general structure of the IS, logical schema of the database, user interface, then the software prototype currently under development.

3.1 Methodology used for data structuring

The methodology used for structuring the data, provided by the analysis of the answers to the questionnaire, is close to the structuring proposed by the *American Concrete Institute Committee 126 « Database Formats for concrete Materials Properties »*, described in the report (Kaetzel and Galler 1997), aimed at defining a framework for cross-referencing cement properties, data and other information. This format has seemed to us generic enough, powerful, simple and well suited to computerised databases and WWW interfacing to be customised to our needs (Dubois *et al.* 1998).

- **Basic principles for data structuring:** information related to products and materials is represented using similarly complete sets of data, all of them together constituting the material and product database, using the following concepts, separated in abstract data type (ADT) and concrete fact (CF):

- **object** (ADT): item selected on a « column »: highest level of hierarchy;
- **constituent** (CF): 1st level detailed information about the object;
- **meta-segment** (ADT): set of information of the same nature related to a constituent;
- **segment** (CF): subdivision of the meta-segment: table of data, definitions, figures;
- **meta-element** (ADT): collection of information of the same kind;
- **element** (CF): item of information.

The SYDOX methodology can deal with a special gateway concept used to connect heterogeneous data sets (Dubois and Fraou 1998). In the present project, different ontologies have to be interfaced. In fact, the mapping of the description of concrete elements (composition) with its related properties (description, regulation, safety measures, standards, etc.) is achieved through a standard ordered hierarchical graph whose nodes are either primitive or reference properties (environment, etc.) and formal properties (certification, etc.).

Figure 1 gives an example for the concept: « shape » of a « window »:

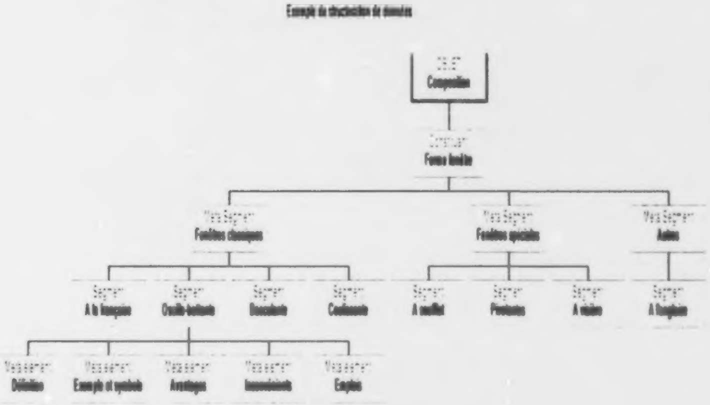

Fig. 1: example of data structuring: shape of a window

For each concept, the number of related sub-concepts has to be kept low enough, to keep visible the possible selections (headings) on the menus of the screen.

3.2 Structure of the SYDOX/MATCOMP/Xi information system and software prototype

The general structure of the information system prototype corresponds to the schema represented on the Figure 2. The following features are considered:

- **a database**: containing the information about products and materials. The organisation of the information has been described above (paragraph 3.1);
- **a data dictionary**: to provide, when needed, a correspondence between the concepts handled by the scenarios and the data put in the database.
- **a user interface**: way of accessing the system, according to the type of user: general information on products, architect wishing a precise detail about properties of a product, technical engineer wishing to get specific information (e.g. thermal behaviour), use for new construction, or for refurbishing; this user interface includes:
    - **an information menus**: headings, as possible choices, resulting from the analysis of the answers to the questionnaire;
    - **some scenarios**: pre-defined « navigation routes » within the information system, that users will then have to follow, today it is pre-determined. Addition of dynamic features to the current software system would allow decreasing their rigidity. For the examples mentioned in the prototype, we choose scenarios coming from several

stages of the life cycle of the construction; those are part of a special computer aided interface (Genthon and Resident 1998);

A communication interface through Internet is being developed. The corresponding information system is an interactive, hypertext software, accessible through HTML browsers such as Netscape Navigator™ or MS-Internet Explorer™, provided that they are able to handle Java applets.

To date, most of the developments have been focused on applications to specific products such as a window and floors, for the following reasons:

- since the aim of the project is to validate a methodology, it seems better to restrict to a product, but to fully develop all the related information;
- however, we will try to also develop a second example, in order to be sure that the behaviour of the first example is not a unique case;
- the validity of the answers provided by the system heavily relies on the amount of information put in the database. Since this information did not previously exit under this format, we also have to build on the contents of the database;
- Moreover, the final product will provide, in a computer aided interface, help to designers or specific users (environment, comparisons, aesthetics, emerging concepts), which will be coupled with the technical database oriented to a search of construction industrial components and information to use them.

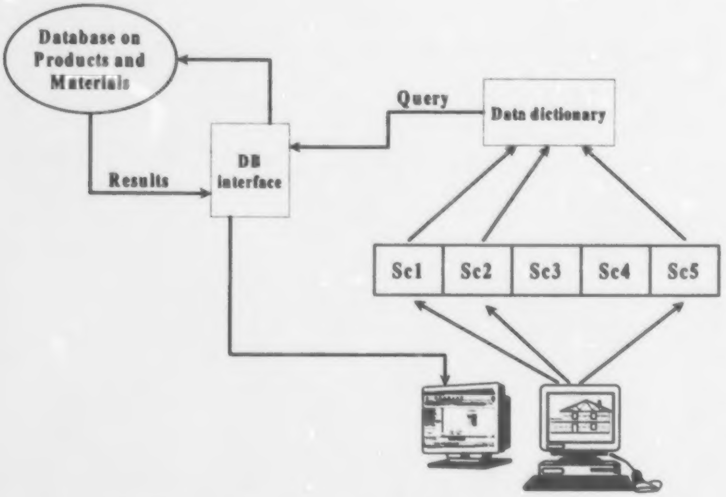

Fig. 2: structure of the SYDOX/MATCOMP/Xi information system

The Figure 3 below shows an example of a screen corresponding to the selection of the following headings (on the example of a window):

- upper menu (« object »): « ***composition*** »: (constitutive elements);
- left menu (« constituent »): « ***formes*** »: shape;
- lower menu (« meta-segment »): « ***classiques*** »: classical;
- right window (« segment », « meta-element » or « element » depending on the structuring of the information): properties, usage, characteristics.

The IS also offers the possibility, once selected *Composition/Produit* (constitutive elements/product) then « *fournisseur* » headings (supplier) to get a list of products classified according to given properties.

To date, several scenarios have been developed; they are currently being translated into the database query format:

- **windows**: scenarios for an architect (new construction and refurbishing); scenario for a thermal engineer (thermal evaluation of a window).
- **floorings**: scenario for an architect, scenario for a contractor, or scenario for a client.

Their aim is to help the user of the software system to select a component (window, or flooring system), taking into account considerations imposed or restrictions on the product due to the nature and the specifications of the construction.

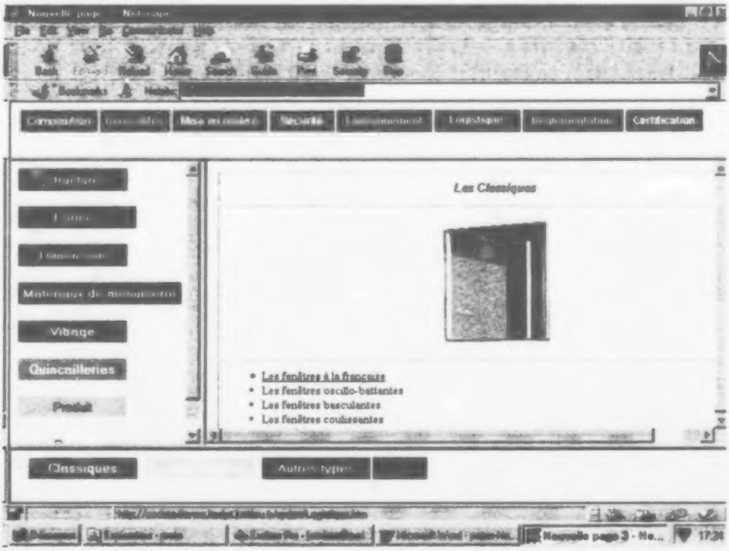

Fig. 3: Information menu for a given selection of headings

4 Use of the information system, trends for the future

4.1 Use of the information system

The first matter arising is related to the nature of the industrial sector targeted by the IS: the building and construction sector, characterised by the number and the diversity of the actors involved. In this sector, the expertise and the communication between the actors are essential, consequently, a will of computerisation of the sector will require work of different natures:

- *definition of data models* for « strong » data in order to enable their circulation through various software environments;
- *availability of « complex » data* (as a kind of « *data self-service* ») for an expert interpretation from the actors;
- circulation between those data, complex data allowing to generate « strong » data as they enter professional domains and become validated by the actors;
- *integration of all the interfaces* into the same environment enabling an on-line access to the different knowledge bases.

Today, it becomes more and more necessary to adopt a pragmatic approach, that is to accept the complexity of the data as such, but also their « *evolutivity* ». This approach must also be systemic, based on classifications, thesaurus, and ontologies in order to be associated to standardised data models as they are developed.

4.2 Trends for the future

Several trends appear for the future of the IS. Among them, let us mention:

- *extension of the software prototype* to other products than those dealt with today, in order to increase the completeness of the system, but also the validity of the implementation already made: this will need an important work in terms of the information to be put within the database;
- *development of « less rigid » scenarios*, enabling questions (from the end-user) closer to the reality of the problems met by professionals, issuing in Artificial Intelligence (AI) oriented approaches, to deal with the incompleteness and lack of consistency of the « human » way of reasoning; and take in account progress in management and retrieval of complex and heterogeneous data (Bestougeff *et al.* 1998).
- interfacing with professional information providers external to the information system, notably by means of current Internet facilities;
- follow-up of standardisation work in the domain of product data exchange, business data interchange, possible use of those standards for setting up relations between SYDOX and distributed IS;
- work on a possible transfer of the SYDOX/MATCOMP/CONST software system to other industrial sectors facing similar problems for handling their numerous product and component data.

5 Conclusion

This project appears as an interesting approach for « *structuring* » complex information, « structuring » being taken with the meaning of enabling a « *smart* » and efficient access to information bases. From that point of view, if the methodology developed seems efficient, this IS could be of a great interest for a lot of people, since, particularly in the building industry, all the professional actors involved in the construction act experiment similar kinds of information problems. Maybe the problem is more crucial in construction, where the communication mainly relies on « human » features, where the teams are never the same or made with the same partners, where discussions often include an important expertise and nearly always need compromises for reaching agreements.

Products, components also follow very quick evolutions, it becomes more and more necessary to adapt the software tools to this evolution.

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274 PROCESS MODELING FOR PLANNING AND MANAGEMENT OF FACILITIES: A RE-ENGINEERING APPROACH

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Abstract

This research had two major objectives. The first was to determine and evaluate the factors required in facilities management and the effect of business type on them and the second was to develop and test a model for management of facilities based on the factors. Factor evaluation revealed that for 76% of the factors there were no differences between the respondents regardless of business affiliation. Where there were differences they hinged on business specific process dimensions. The results of the factor analysis and the basis of the factors used in the analysis enabled the conclusion that the resultant factors are important in facilities management.

A facility management model made up of process, need, service delivery and assessment sub models was created. The model represents the facilities management environment via three variables namely, real time needs, real time status of the facilities and service concept. In field tests, the model was found to be both effective and efficient at handling management information.

Keywords: Management, process modelling, re-engineering, serviceability, performance, and assessment

1 Background

There is increased complexity and dynamism in customer needs spurred by more awareness of rights caused in part by information technology. In response to this, more change responsive and effective paradigms are required to understand needs and deliver products or services. The manager of facilities must have a way of identifying and understanding needs and the relationship between processes and facilities.

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Business opportunities and product development cycles of many high value products now have such short duration of even 2-3 years and the time to market often determines their economic viability and profit margin [LIFE RC, 1995]. Rapid delivery of facilities through retrofitting or new construction is an important competitive tool for such firms. Ensuring real time appropriateness of the facilities is just as important.

The Architecture, Engineering and Construction (AEC) industry with its ubiquitous nature is one of the largest industries. In Finland it accounted for a Gross National Product (GNP) of about 15% in 1997 [Tilastokeskus, 1998]. An improvement in the life cycle processes in the industry has a potential to result in cost reduction and benefit an economy as a whole.

1.1 Research problem and formulation

1.1.1 Problem analysis

Although facilities management has been recently identified as being an important corporate function [Stephens, 1994], the factors that should be used in the management process are not very clearly expressed in research. There are no models that deal effectively with information handling or categorisation and into physical tangibles and use factors, an approach that has been found to be useful in facilities planning phase. Evidence from the field indicates that existing models have very large views and are often ineffective at handling the usual chores of facilities management [Barret, 1995]. The effect of these problems is that facilities management is often carried out with unstructured or even partial information.

1.1.2 Formulation

The facilities management paradigm should be simple to apply but with clear responsibilities which include compliance with business requirements. The method should be effective at linking the systems and parts of the facilities to the needs. To achieve these requirements the facilities management model should have the following capabilities:

1. A means of analysing the processes of management to establish a functional design
2. A means of determining the required service levels or need levels to satisfy the requirements of business
3. A means of delivering service detailing the factors that are required to enable the delivery of the defined service
4. An assessment module for checking the effect of change in the facilities

This study had two main objectives. The first was to study the factors required in facilities management and the effect of business type on them and, (2) to develop and test a model for management of facilities based on the factors.

1.2 Theoretical framework

A management system was required in which the needs of the stakeholders are determined and balanced with the available resources. This system was determined by using the defining factors of objects. LIFE RC (1995) and Pena et al (1987) give the definition of engineering objects in terms of the following three factors:

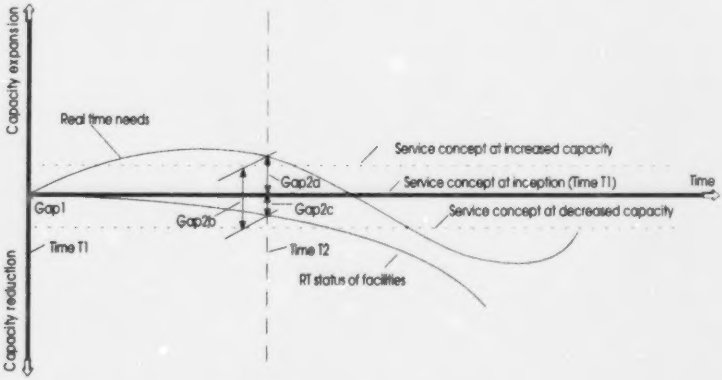
1. Function - referring to design intent obtained from the client, code jurisdiction agency or common practice

2. Form - describing abstract geometrical or structural features of design including material specifications
3. Behaviour - referring to values of the form attributes like deflection energy use or project cost.

Supply and demand factors at the utilisation stage are governed by the same factors.

1.2.1 Research variables

Choice in a project is based on a working equilibrium involving the three variables. At feasibility stage the three factors represent possibility, desirability and managerial issues. At utilisation phase they are performance, serviceability and managerial or service concept. At a control phase like a costing stage the factors are tangibles' cost, user costs and managerial costs. This study uses the three variables as the basis for management and control for supply and demand factors in facilities. The dynamic nature of business means that established facilities set-ups only result in a moment in time satisfaction of needs. As time progresses, gaps may develop between supply and demand. Figure 1 illustrates the relationships among the three research variables with time. The real time status line represents the current or real time status of facilities. The line shows the facilities to be gradually deteriorating until they reach a failure point. This deterioration is due to ageing or other obsolescence factors. Needs of the stakeholders are represented by real time needs line. This line shows the usual fluctuations in the business environment. A horizontal line represents the current planned level of facilities or service concept. This service concept remains constant until it is changed. A new service concept may result in bigger or smaller facilities and is represented by horizontal lines above or below the original service concept as indicated by the dotted lines.



Capacity expansion
Real time needs
Service concept at increased capacity
Gap2d
Service concept at inception (Time T1)
Time
Gap1
Gap2c
Service concept at decreased capacity
Gap2b
Time T1
Time T2
RT status of facilities
Capacity reduction

Fig. 1: Relationship among research variables with time

The lack of fit between supply and demand factors during the utilisation phase is represented by gaps between the values of the variables. T1 represents a moment in time when the facilities completely satisfy the needs and therefore there are no differences in value among the three variables. At time T2 there is a gap in the supply-demand relationship. The supply-demand mismatch is represented by three gaps. The gaps are analysed below.

1. Gap 2a between the **service concept** and the **real-time needs** indicates the extent of the relevance of the service concept or plans to the current needs
2. Gap 2b between the **service concept** and **the status** values indicates the extent of the compliance of the physical tangibles or performance factors to the plans or service concept.
3. Gap 2c between **real time needs** and the **facilities status** indicates the extent of the appropriateness of the physical tangibles to support the current needs

The gaps represent what the managers must do to ensure facilities' appropriateness. The solution can take the form of either changing the status or the service concept or both. Because the service concept is directly related to the business process, a change in it requires re-examination of business process. The modification of status factors on the other hand involves the improvement of the physical tangibles and services to restore them to the intended service levels.

2 The proposed facilities management model

The proposed model is composed of four sub models namely process, need, delivery and assessment models. The model is illustrated in Figure 2. The description of the components of the model is given below.

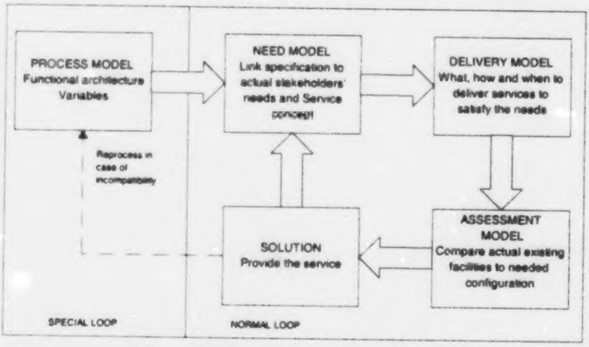

PROCESS MODEL
Functional architecture
Variables
NEED MODEL
Link specification to actual stakeholders' needs and Service concept
DELIVERY MODEL
What, how and when to deliver services to satisfy the needs
Reprocess in case of incompatibility
ASSESSMENT MODEL
Compare actual existing facilities to needed configuration
SOLUTION
Provide the service
SPECIAL LOOP
NORMAL LOOP

Fig. 2: The facilities management model

Sub-model 1: Process model. The process model is a functional architecture for defining facilities management activities and management information. The model was based on IDEF0. The process model is not an everyday management model. It is useful in the case when complete reconstruction or major changes in the processes of business take place. Figure 3 shows the first level of the process model. Details of the process model can be found at reference (Ojwaka, 1995).

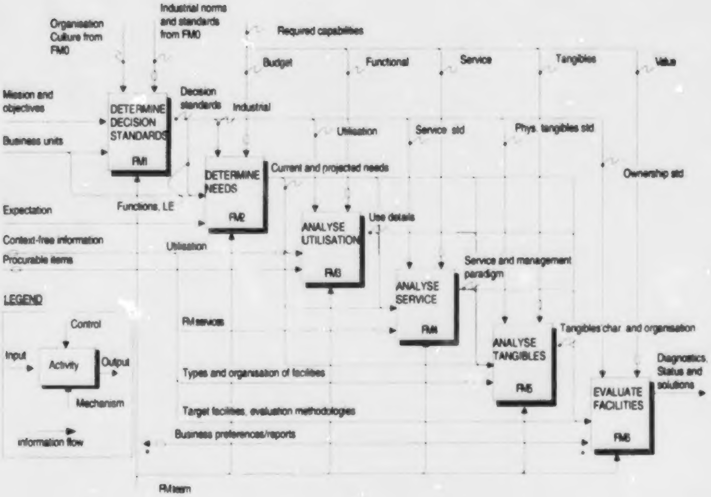


Fig. 3: Facilities management process model main level

Sub-model 2: Need model. The need model is a framework for determining the needs of the stakeholders based on process model. Need is an inventory of systems, parts and services necessary for the utilisation of facilities. Two types of needs are identified by the need model. They are the real time needs and business dictated requirements or the service concept (SC). Service concept is a level of service that has been adopted by the business. It is based on a snap shot of needs at a moment in time. Apart from needs of stakeholders, it is also based on funds in form of grants for running the facilities, process dictated requirement, management's own recommendations, importance and compromise levels for the objects and stakeholders needs. The value of the service concept is constant once it is defined and is only changed when a new plan is devised. Real time needs are the needs of the stakeholders during the course of the utilisation of the facilities.

To define the needs, the process model information is classified into objects, their functionality and occupancy or behaviour factors. The required system constraints like costs, time, capacity, quality, links etc. are used to establish the required elements of the objects, functions and occupancy factors. Typical first level need model analysis factors are shown in Table 1.

Table 1: Typical need definition factors

Constraint	Objects	Functionality (As designed)	Occupancy (As used)
Costs	Maintenance costs	Work design costs	Utilisation costs
Time	Support for required schedules	Support for functionality	Delay, Support for work design
Capacity	Physical size	Useable sizes	Work design sizes
Quality	Object performance quality	Serviceability quality	Serviceability quality
Links	Sys. links	Shared resources	Shared resources

Sub-model 3: Delivery model. The delivery model delivers the defined services on the basis of the need model to match needs and available resources. Every demand is compared with the supply prior to its implementation. The model defines the items and activities, which according to the process information are required to deliver the defined facilities management service and comply with the supply and demand issues.

Sub-model 4: Assessment model. The assessment model determines the needs of the stakeholders and compares them with both the status and the service concept. On the basis of the comparison, the model creates a report that details the gaps between supply and demand and also gives a recommendation on the course of action to rectify the situation.

3 Methodology

3.1 Factor determination

An initial factor list was created based on literature study of extant theories and practices to take care of utilisation, physical tangibles and the necessary standards and controls. These factors were partly derived from process management requirement which defines management functions as being primarily planning, improvement and control [Soares and Anderson, 1997; Juran, 1992; Shaw et al, 1988]. The initial factor categories are discussed below.

1. **Standards** examined strategically important issues for facilities management ranging from physical tangibles to utilisation and services
2. **Needs** examined requirements in terms of the usual problems in facilities, causes of these problems and solution selection criteria
3. **Utilisation** factors examined use dimensions like work design especially flexibility and other rates of use issues along with the effect of change
4. **Service** factors examined the functions that facilities management should carry out to ensure serviceability
5. **Physical tangible** factors investigated the business implementation environment for the relationship between facilities items and the processes of business
6. **Control** factors investigated issues of assessment for facilities including remedial actions and their impact on the facilities

Two instruments were used in the factor study: questionnaires and interviews. The value of the factors and their potential for use in everyday project and facilities management was sought. Four measures namely importance, expectation, rate of use and effect were used to judge the factors on a five-point scale.

The factor establishment exercise targeted those professionals involved in management of projects or facilities in organisations. The respondents were divided into two categories of profit making and non-profit making firms. The source for the profit making firms was the listing of the 500 top firms in Finland in 1995 from data on public firms. The source of information for the non-profit firms was a listing of public institutions including public colleges and institutions of higher learning, public hospitals and public libraries. Based on the population, a sample size of 10 percent was judged to be representative of the population under study [Campbell, 1987]. A total of 120 short listed firms were called and requested to participate in the study. Roughly 100 firms accepted the challenge and received the questionnaires. A total 72 filled questionnaires were returned on time.

3.2 Model testing

Model testing sought suitability and importance rating values for the three variables of facilities management. These values were then used to assess the facilities and hence determine the effectiveness of the facilities management model. The questionnaire was used obtain real time needs and the service concept on the scale of 1-5. Preiser (1972) showed that user response to a serviceability survey is a valid way of obtaining information on the serviceability of facilities. The real time status was obtained by condition surveys, questionnaires, measurements or by use of appropriate as built drawings. The relationship between the serviceability items and the performance items as expressed in the need model was used to identify those status items that needed to be assessed. A chart was developed for use in displaying the results together. The facilities were divided into building, space and service elements for the purposes of the assessment.

4 Analysis and results

4.1 Factor analysis

There were six original categories of factors and each with sub categories representing 231 factors. There was a strong indication that the vast majority of the respondents regarded the factors as being relevant for management. Both the median and standard deviation indicated this. For most of the factors the median was of the order 3 and above. To further investigate the factors the number of respondents finding the factors useful was determined based on responses of 3 and above. 54 factors were rated as being unimportant representing 23.4% of the total. T-tests analysis revealed that for 76.8% of the factors there were no significant differences between the respondents. An examination of the factors where there are differences revealed that the differences hinged on business specifics and how they influence management. On the basis of the factor analysis, a set of factors was elicited from the original factors. Principal component analysis generated a total of 99 factors to replace the old factors in the original questionnaire. In the factors analysis the relative importance of the factors can be seen in the fact that most of the original factors formed part of the new factors. The result of the analysis of the factors was a set of factors that were applicable to facilities managers.

4.2 Analysis of test facilities

Table 2 shows typical results for one of the facilities studied. It shows the average suitability and importance ratings for a building, space and services expressed in point form in a scale of 1-5. A low rating is an indication of unfulfilled needs. So a highly rated item compared to a lowly rated item simply means that the lowly rated item has a higher need for attention than the highly rated one. The comparison among the three items compares this demand. It is this demand that is a trigger for action.

Table 2: Average overall assessment results of typical facilities

Facility element	Real time needs		Service concept		Real time status		Overall diagnosis
	Suitability rating	Importance rating	Suitability rating	Importance rating	condition rating	Importance rating	
Building	3.2	3.6	3.5	3.2	4	3.3	Serviceability, functional and Communication problems
Space	2.9	3.8	3.4	3.4	3	3.6	Serviceability problems and deterioration of objects.
Service	3.7	3.9	3.9	3.9	-	4	Service concept does not support needs.

Assessment results indicate as shown in Table 2 that users were not very satisfied with the building. A rating of 3.2 implied that many aspects of needs remained unfulfilled. The average user satisfaction level for the building hides the fact that there were some four items that were rated below 3, a level below which the facilities need some attention immediately. The affected items were functional appropriateness of the building, parking space availability, building thermal comfort and air quality. The management of facilities had alluded to the parking problem during the data gathering time but the other serviceability problems were not apparent to them. It was interesting that the management still rated the parking space availability as being good (4). Management was also slightly more satisfied with the building than the users with a rating of 3.5 but has still relatively many unfulfilled needs. The service concept was not quite satisfied by the building. The status measure of 4 suggests that the physical tangibles and other performance items are generally satisfactory.

The result of the comparison of the three variables together indicated that for the building, plan and objects do not support serviceability – they are functionally inappropriate. There were also communication problems. In addition there was a slight service delivery problem. This refers to the case when business rates the facilities at a higher level than the users. It simply means that the service concept is not translated into satisfaction of the users needs. Because the status is rated at value 4 yet it does not translate into similar satisfaction rating for the users nor the business, this may mean that there is a higher demand on the status items. Than in the past.

Generally all the cases with ratings of near or below the value 3 should be targeted for remedial actions. This would depend on how easy it would be to repair the problems. In the building example shown in Table 2 all the items with the exception of circulation spaces in the building and parking space problems can be fixed easily. When any status items are repaired, there is no guarantee that the users will be satisfied. For a complete solution of the problem, the other two variables must be combined with the status results. The delivery problem can be addressed by making sure that what is planned is delivered. The problem of higher current demand is a problem that has ramifications for the plan or the service concept. It requires the service concept to be re-examined preferably via the process model in order to solve the problem effectively.

The field test indicated that method was easy and could be applied rapidly and at negligible costs. The field trials indicated that the model was able to determine quality issues for the facilities in more details than the facilities managers had been familiar with. By an importance rating, the managers valued the assessment items used in the facilities case studies as being of average importance rating of greater than 3. No differences were observed in difficulty of applying the model to facilities with operating management systems and those without. Results show that the analysis of one of the facilities confirmed management plans already underway of improving the facilities.

5 Discussion

5.1 Results

The **factor** evaluation had the objective of eliciting the factors that should form the basis for the management system. These factors were based on form, function and behaviour classification system. The question of what information should be used in facilities management is answered by these factors. Despite variations between firms, the factors used here are considered to be useful. The factors mirror factors used by other researchers like Baird et al (1990), Davis (1994), Lewontin et al (1990) and IFMA, 1993. Not withstanding business and national cultures, it can be said that good management practices remain universal and basically the same. It is this basic value that the factor analysis sought and determined. The sample size indicated that the results were a good representation of the population and hence the feelings of the facilities managers at the time of measurement. It is however conceded that results are influenced by the business expediency at the moment of measurement.

The **proposed management model** represent in general the functions of process management of planning, improvement and control as espoused by Juran (1992). The research model proposed that (a), the research variables are subject to different forces and hence change differently and (b), only a combination of the three variables provide the total picture required to ensure that both the serviceability and performance factors are taken care of in facilities management. The model assumed that when the three variables namely the real time needs, service concept and the status values converge at the same value then the item of facilities that they are referring to have an ideal supply demand relationship. From the results it can be seen that the three variables had different values as envisaged by the theoretical model. This bears out the fact that change, which has obviously occurred in the facilities, has caused differential effect on the variables. The theory proposed that only a combination of the three provided a correct assessment of the facilities. This can be seen in the fact that the values held by the variables seem to contradict each other. An isolated reference to one of the values value would obviously lead to erroneously interpretation of the situation in the facilities.

The FM model was proposed as the instrument for applying the theory. The effectiveness of the model is its ability to enable the addressing of the problem on hand. The model proved to be an effective tool. It usefulness is partially displayed by the importance rating give by the stakeholders on the management variables and their importance to management. These rating are compatible with factor study results, which also largely found the factors to be important.

Management by fact is a key requirement of TQM. The facilities management model sought to provide the control handles that would enable the realisation of this requirement in facilities management. The model takes care of needs of the stakeholders regardless of their position in the importance hierarchy at the facilities. The needs of the stakeholders are compared to both the plans for the facilities and also the current status of the facilities. Specific parts of facilities serviceability or performance could be targeted. This fact solves a perennial problem of management pointed out by Barret (1995) that many existing models are very large and inappropriate for individual issues.

A management paradigm is as good as the quality of information that it uses. The information should be relevant and enable decision-making. The information used in the management of the facilities is derived form the firm's own process information. The findings from the case studies indicated that the facilities management Model is both effective and efficient at handling the information required in facilities management and provides relevant decision making information.

The research has relied on the existing scientific methods in its approach. The data collection, its analysis have relied on existing norms. Any differences are only due to the circumstance of the place of the research. The analysis method selected which comprised descriptive statistics for data classification, T test for determining differences between sample and hence populations' means and the principal component analysis for factor analysis are common methods. Both the methods have been used widely in research. A recent use of factor analysis was by Soares and Anderson (1997) and Ahmed and Kangari (1993). The results of the factor analysis and the basis of the factors used in the analysis enable the conclusion that the resultant factors are valuable in facilities management.

On the basis of the case studies it is clearly apparent that the theory has been tested and is applicable to facilities management. In addition the proposed model is a suitable vehicle for the application of theories.

5.2 Limitations

The scope of this study is limited to determination of factors of facilities management and the process of controlling them for decision-making purposes. It details how management information should be determined and handled in changing circumstances. The management of business functions housed by the facilities and their processes is not considered covered by this research. While the principle activities of facilities management are given as envisaged by the model, their management process is not covered.

A knowledge of what constitutes business needs in facilities, the end users needs and also the status of the facilities at the time of evaluation must be known in order for the management system to work. The later two are easy to obtain. Business needs requires more effort to obtain. It may place some limitation on some managers.

5.3 Theoretical and practical implications of the research and further work

The facilities management model is primarily aimed at objective setting, determination of needs, identification of problems and the organisation of information. It should therefore be useful in the definition of any product regardless of the industry. In particular it should be very useful at identifying quality issues for the product involved. In such a case the product would be defined by using user needs, management goals and constraints of the actual market being the third variable.

Further work on the model could include:

1. Allocation of funds for facilities management on the basis of the values held by the model variables can be investigated to base the allocation on supply and demand factors of use.
2. The process model used here is a TO BE model or a functional architecture. A more comprehensive facilities management model should also include a framework for obtaining, AS IS process model to enable determination of reasons for problems and hence more effective service concept designs.

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275 THE PRACTICAL NEEDS OF INTEGRATING SCOPE, COST, AND TIME

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Abstract

The primary goal of tracking scope, cost, and time throughout the construction process is to facilitate the early detection of problem activities that are running over budget or falling behind scheduled progress. Current practice tracks this information using separate processes, which leads to inconsistencies between the information and inaccuracies when determining the cost and schedule status. Project managers need an integrated suite of project management tools so that the project's scope, cost, and time are in sync and the work in place is accurately reflected in the project control system. In this paper, we will provide a case study that demonstrates the practical needs of project managers to support integration throughout the life of a project. We will also demonstrate how those needs are not being addressed by existing software tools, by standards developed for the project management domain, and by information models that have been developed in research. This paper will show that the following issues must be addressed to enable the integration throughout the construction process: the information must be integrated at the start of construction; the mapping scheme between the different hierarchical representations of scope, cost, and time must be defined; and the shared information must be defined.

Keywords: cost control, integration, schedule, project, construction, scope, design

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1 Introduction

Integrating design, cost, and schedule information is not a new concept. Researchers and practitioners alike have been discussing the need for integration for decades. In 1985, the ASCE issued a report on Construction Cost Control that stated "the data collected for cost control (man-hours, cost, quantities of work performed) can be utilized for updating the schedule and can be utilized for earning calculations. This multiple use of data contributes to the overall accuracy of reports and significantly reduced the manual effort to enter data" (Carty 1985). However, despite technological advancements in the last 15 years, design, cost, and schedule information continues to be generated and maintained using separate processes, which continues to produce inconsistencies between the different types of information. Today, project participants update and maintain their part of the project control system based on their understanding of the project's status using the application that suits their needs. In an ideal world, contractors would enter information once, the project control system would be updated to reflect changes, and the project's cost and schedule status would be easily obtained. The solution to this problem would be to integrate the suite of project management tools so that the project's scope, cost, and time are in sync and the work in place is accurately reflected in the project control system.

So why are we still working in this less than ideal environment? Why is it so difficult to integrate this information? Our research addresses these questions. In this paper, we will discuss the following:

- the integration that is supported by information models developed in research, standard object definitions, and existing software tools,
- the issues that make integrating design, cost, and schedule information throughout the construction process difficult, and
- necessary research.

1.1 Practical motivation

Imagine being in the shoes of the general contractor who is responsible for constructing a highly technical building project for a pharmaceutical company. The project is under tight schedule constraints, requiring completion in nine months. In this example, we will be focusing on the foundation work but similar issues exist for all types of work. You have decided to self-perform most of the concrete foundation work, which consists of spread footings, grade beams, and a slab. Your direct work includes foundation excavation, concrete placement, and formwork, as you have subcontracted the reinforcing steel and concrete finishing. Consequently, as the general contractor, you are focused on controlling costs for your direct work, monitoring costs for subcontractors for billing purposes, and tracking schedule progress for all the work. You have allowed six weeks in the construction schedule to complete all the foundation work. As the foundation work approaches the fourth week of schedule progress, you might ask yourself:

- Do I have enough money in the budget to complete the foundation work?
- Have I allowed enough time in the schedule to complete the foundation?
- Is there enough time for my subcontractors to complete their work?

Contractors rely on their project control system to help answer these questions and facilitate the early detection of problem activities that are running over budget or falling behind scheduled progress. Project managers spend extensive amounts of time tracking costs and mapping them to the appropriate cost code, tracking quantities and measuring resource performance, and updating the construction schedule. Project managers use this information to forecast their total cost, which is based on the progress to date and costs incurred to date, and forecast their scheduled completion date. Yet how can contractors rely on these forecasts when there is no explicit relationship between the scheduled progress, resource performance, and the forecasted cost? Contractors track quantities to evaluate resource performance, yet this information is usually not explicitly related to the corresponding activity's progress. Contractors need to know the current schedule progress to forecast the total costs, yet there is no explicit relationship between costs and schedule status. Moreover, the information is generated and maintained by different people who organize the information in different ways to support their view of the project. In summary, contractors need a flexible yet consistent approach to model and track this information.

In the next section, we will describe previous research and standards developed to support the integration of scope, cost, and time throughout the life of a project.

1.2 Technological motivation

There has been a significant amount of research on integrating design, cost, and schedule information. The focus of these research efforts varies from developing construction information models to developing prototype systems that support integration (Luiten et al. 1993; Luiten 1994; Aouad et al. 1994; Björk 1992; Froese 1992; Tolman, Bakkeren and Böhms 1994; Stumpf 1996; Tracey 1996). Froese (95) summarizes some of these research efforts and the conceptual models that have been developed to support computer integrated construction. In addition, substantial progress in developing standards has been made in the past several years. The Industry Alliance for Interoperability (IAI), an industry-based consortium, is developing standards for exchanging data between computer systems within the AEC industry in the form of Industry Foundation Classes (IFC's) (IAI 1998). These standards explicitly define the design components and the relationships between scope, cost, and time.

These research efforts and standards have laid the groundwork for developing integrated systems by describing the information that needs to exist and providing conceptual models that describe the relationships. These conceptual models represent a system-based approach that provides a structured framework for integrating scope, cost, and time. Such structure, however, does not allow project managers the flexibility needed for managing and sharing this information for the life of a project. Specifically, these models and standards do not formalize the relationships required to maintain integration as the information changes, share information that is represented at different levels of detail, and support integrated time and cost control. In this paper, we demonstrate the need for these relationships, describe the relationship classes that must be provided, and identify the relationships that previous research and standards have not modeled.

Through case example, we illustrate the needs of project managers for integrated information and the modeling requirements to enable integration throughout the construction process. Specifically, we show that the following issues must be addressed to provide an integrated model:

- the information must be integrated at the start of construction,
- the relationships between the different hierarchical representations of scope, cost, and time must be defined, and
- the shared information must be defined.

In the following sections, we will discuss each of these issues and the related research opportunities.

2 Integration of scope, cost, and time prior to construction

Contractors must have an integrated scope, cost, and time model at the start of construction to maintain integration as construction progresses. If there are inconsistencies between the scope, cost, and schedule information prior to construction, then this information will never be in sync as construction progresses. We looked at the U.S. software market and picked the best suite of tools and tested their integration capabilities on an actual construction project (Staub et al. 1998).

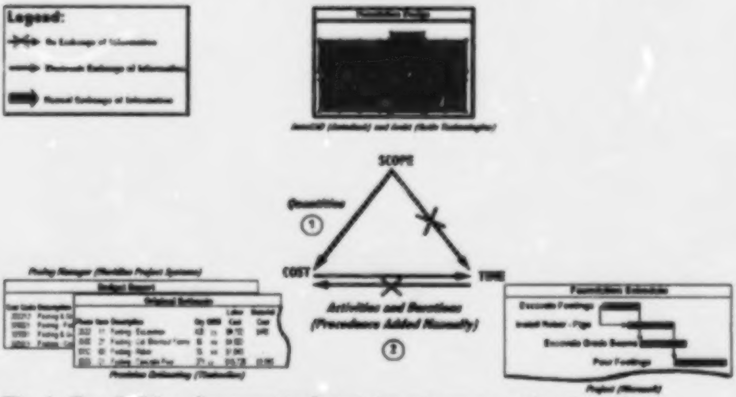


Fig. 1: Capabilities of current tools to integrate scope, estimate, and time

The next sections will show that existing tools do support integration of scope, cost, and time in an incremental manner. First, construction costs were estimated using the quantities from the CAD model (step 1 in Figure 1). Next, the schedule was generated from the cost estimate by converting estimating items into schedule activities (step 2 in Figure 1).

2.1 Design-cost integration

The estimator linked estimating items and work packages with graphical objects in the CAD model and quantities were automatically calculated and inserted into the estimate. This link ensured that the project's design and costs were in line at the start of construction. However, the link only supports a one-to-one mapping between design and cost information because only one work package or estimating item can be attached to each design object. In addition, another limitation is that the relationship between the design and cost information is uni-directional. Consequently, the estimator cannot query the estimating items to determine what design object it was derived from.

2.2 Cost-schedule integration

The planner selects the estimating item or items that will become a construction activity, and the activity durations are automatically calculated based on the productivity rate. The planner then opens the file in the scheduling program and manually adds the precedence relationships. The cost-schedule link ensures that the resource assumptions made during the estimating phase are incorporated in the planning stage.

However, if the design or resources change as construction progresses, the activity durations must be updated manually. In addition, there is no explicit link between the schedule activities and the estimating items after the schedule has been created. Each activity doesn't know what estimating items it was derived from or what resource productivity rates were used when the duration was calculated. Finally, there is no inverse relationship between the schedule and cost. Consequently, if an activity's progress takes longer than expected, it is not reflected in the cost estimate.

In this integrated environment, and in many of the conceptual models developed in previous research, the relationships between scope, cost, and time are represented by a single arrow, as shown in Figure 1. However, when looking at this information from the user's perspective, we have found that the structure of this information and the relationships between this information is much more complex.

3 Relationships between the different hierarchical representations

As illustrated in Section 1.1, scope, cost, and schedule information is created at several levels of detail. Hierarchies are ideal to represent these different levels of detail and the different types of aggregations and decompositions.

3.1 Design models

The design information generated today is often represented at a high level of detail. The designs depict the final state of the components but do not generally model the materials that compose the final product or the materials that are required to build the product. Software programs have been developed to address the lack of detailed design information represented in design models today. For example, Eagle Point's StrucPro automates reinforced concrete detailing, which would automatically layout the reinforcing steel in the foundation system described above (Eagle Point 1998). In addition, research efforts have also attempted to generate construction product information automatically, such as temporary structures (Aalami 1998).

3.2 Cost estimates and cost control

Contractors generate very detailed cost estimates that are often broken down in many different ways. On the Sequus Project, the estimate was divided into the following sections for all direct work: Area, Group Phase (such as concrete), Phase (such as footing concrete), and Item (such as 2,000 psi concrete). The left part of Figure 2 shows the footing portion of the foundation estimate. Therefore, estimators need to be able to structure estimates using different hierarchical representations.

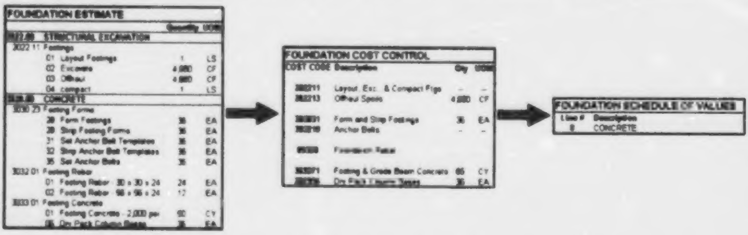


Fig. 2: Estimate, cost control, and schedule of values for foundation

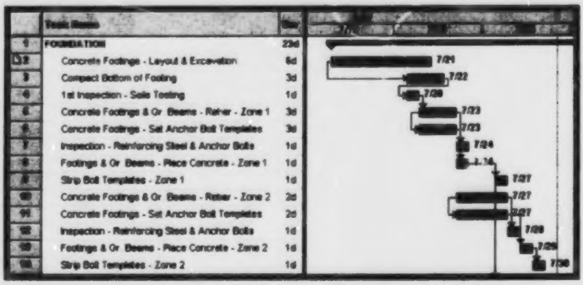
Costs are typically tracked with less detail than the estimates. Figure 2 shows the breakdown of costs for the footing portion of the foundation work, which shows that there are eight items that track the footing costs. To track the footing costs, the project manager created cost items by aggregating several estimating items for the footing work, by aggregating like items from a different part of the foundation work, and by transferring a single item directly from the estimate. Therefore, project managers must be able to aggregate different estimating items to facilitate tracking this information and to obtain the production information desired.

The schedule of values is represented with even less detail than the cost control system. The schedule of values is the cost breakdown of the pay items for which general contractors and subcontractors submit billings each month. On the Sequus Project, all pay applications for concrete work were submitted under one schedule of value, as shown in Figure 2. Therefore, project managers create additional aggregations of cost information for billing purposes.

3.3 Schedule models

Schedules are often generated at multiple levels of detail to support different views of the construction progress. Figure 3 shows the summary and detailed views of the footing portion of the foundation work. In addition, construction schedules are often broken into zones and areas to show work flow. For example, the concrete placement consisted of the aggregation of the footing and grade beam concrete, whereas the reinforcing steel consisted of a decomposition of the work into construction zones. Therefore, project planners and superintendents must be able to aggregate and decompose construction activities quickly and easily to support different planning strategies.

Current tools address this issue by providing summary bars (Microsoft Project) or hammock activities (Primavera). Consequently, the aggregated activity simply inherits the start date of the earliest activity and finish date of the latest activity. Each decomposed activity, however, doesn't know that it is a part of a higher level activity and each aggregated activity doesn't know that it is composed of the lower level activities. Many research projects have addressed this limitation by providing hierarchical planning approaches, such as MDA, Oarplan, CasePlan, and CMM (Jagbeck 1994, Darwiche et al 1988, Dzeng et al 1997, Aalami et al 1998). The Construction Method Modeler (CMM) provides the most promising approach, however, because it represents components, actions, resources, and sequencing constraints ("CARS") at every level of detail. This is a necessary step to support model-based reasoning and enable integration between scope, cost, and time at multiple levels of detail.



	Task Name	[illegible]
1	FOUNDATION	23d
2	Concrete Footings - Layout & Excavation	6d
3	Compact Bottom of Footing	3d
4	1st Inspection - Soils Testing	1d
5	Concrete Footings & Gr Beams - Rebar - Zone 1	3d
6	Concrete Footings - Set Anchor Bolt Templates	3d
7	Inspection - Reinforcing Steel & Anchor Bolts	1d
8	Footings & Gr Beams - Place Concrete - Zone 1	1d
9	Strip Bolt Templates - Zone 1	1d
10	Concrete Footings & Gr Beams - Rebar - Zone 2	2d
11	Concrete Footings - Set Anchor Bolt Templates	2d
12	Inspection - Reinforcing Steel & Anchor Bolts	1d
13	Footings & Gr Beams - Place Concrete - Zone 2	1d
14	Strip Bolt Templates - Zone 2	1d

Fig. 3: Footing portion of the foundation schedule

In summary, design, cost, and schedule information are represented at different levels of detail and have different hierarchical organizations. Consequently, to integrate this information, a mapping scheme must be developed to support the relationships between the different hierarchical representations.

3.4 Mapping scheme between the different hierarchical representations

Figure 1 showed the scope, cost, and time triangle with arrows illustrating the relationships between the information. This representation fails to show the complex structure of this information and the multitude of relationships that must exist to share the necessary information. As the previous sections illustrated, the scope, estimate, cost control, and schedule data are all represented with different hierarchical organizations. Project managers must be able to work with the different hierarchies with changes in each hierarchy correctly propagating to the other. Moreover, project managers must be able to work with the information at different levels of detail and create aggregations and decompositions to support their view of the information. Figure 4 shows the hierarchical representation of the foundation scope, cost control (estimate not shown), and schedule information.

This figure illustrates the complexity of mapping the relationships between these information items. During implementation, we will determine whether a direct mapping between views is the solution versus mapping to and from a core model to derive different views. The relationships shown in Figure 4 need to be classified to ensure the appropriate information is shared and to ensure consistency when calculating cost and schedule status.

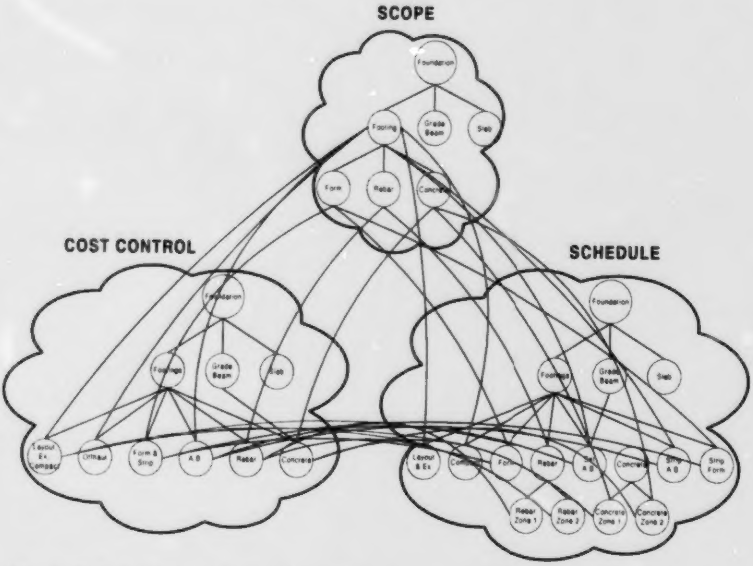


Fig. 4: Relationships between hierarchical representations

4 Classes of relationships and shared information

Previous research and current tools share quantity information and resource production information when calculating costs and schedule status. However, quantity information is not always available, resource performance is not always measurable, and schedule progress is not always derivable from the quantities installed. Consequently, the relationships between the information need to be classified according to the type of information that is shared. Table 1 shows the classes of relationships and the shared information that we have defined thus far. Previous research and standards do not model many of these relationships. Specifically, they do not reify the following relationships: quantity-based relationship between the estimate and cost control; the labor time-based relationship between estimate and cost and between estimate and schedule; and the progress-based relationship between the schedule and cost control information. The following case examples demonstrate the need for these relationships, as project managers must continually determine activity progress and forecast the corresponding costs.

Table 1: Classes of relationships and information shared

Classes of Relationships	Information Shared	From		To
Quantity-Based	Quantity	Design	→	Estimate
		Estimate	→	Cost
		Design	→	Schedule
Labor Time-Based	Resource hours	Estimate	→	Cost
		Estimate	→	Schedule
User-Based	Activity Progress	User	→	Schedule
Progress-Based	Activity Progress	Schedule	→	Cost

In some instances, an activity's progress can be measured by the quantity installed, such as concrete placement and excavation. In addition, an activity's progress can also be measured by the amount of time a labor resource has worked on that activity, such as pressure testing the pipe installed. In contrast, some activities' progress can only be determined through visual inspection. For example, determining the progress of rebar installation can't simply be measured by the pounds of steel that is placed in a concrete slab. The progress of that activity also depends on the spacing of the rebar and whether it has been tied appropriately, which can't be quantified. The user should enter such progress measurement after visual inspection of the work in place. Finally, the cost forecast for a particular scope of work depends on the corresponding activity's progress. Therefore, quantities installed, resources consumed, and activity progress must be shared to support integrated time and cost control and the corresponding relationship classes are necessary to enable this integration.

These relationship classes give project managers a consistent approach to calculating schedule progress and forecasting the corresponding costs. Furthermore, it provides a flexible environment by allowing project managers to work with the information at different levels of detail and to create aggregations and decompositions that support different views of the information.

Our research focuses on determining and formalizing other necessary relationships to support integration of scope, cost, and time throughout the construction process. We will demonstrate the usefulness of these relationship classes by implementing and testing software prototypes on actual construction projects.

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PART TWENTY-TWO

VIRTUAL REALITY AND HUMAN–COMPUTER INTERACTION

276 THE DEVELOPMENT OF AN INTEGRATED LIFE CYCLE COSTING MODEL USING OBJECT ORIENTED AND VR TECHNOLOGIES

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Abstract

There is an increasing realisation of the importance of operation and maintenance as opposed to capital costs throughout the life of an asset. In addition, new styles of contracts such as PFI (Private Finance Initiative) are becoming more popular. This will require that the building product is addressed within its holistic picture including the design, construction and maintenance. It is therefore vital to embed the life cycle costing element of a facility within its design and construction. Whole Life Costing is a technique used to facilitate effective choice between alternatives in the search of economic solutions. Information technology, particularly integrated databases and VR (Virtual Reality), can provide the mechanism to facilitate the integration of the whole life cost information.

The research project described in this paper aims to add a life cycle costing element to the design phase of the OSCON integrated database developed at Salford University in the UK. The current integrated database within OSCON supports the functions of design, estimating and planning. The proposed system will allow the user within a VR environment to navigate inside the building retrieving information about building components that need replacement or repair. A colouring mechanism will be developed to show various elements in different colours according to cost criteria. This would allow the user to easily inspect the building and get rough ideas of repair and maintenance programmes, running costs and cash flows. The system will allow data to be updated continuously so that it will enable the comparison with initial plans and estimates and provides a fresh view of future action and feedback.

Keywords: life cycle costing, information technology, virtual reality, construction projects.

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1 Introduction

Design for whole life cost is becoming a major issue in the construction industry. The days where the asset was separated from its use are over. Whole Life Costing provides an opportunity to integrate design, operation and maintenance information. Whole Life Costing is an evaluation tool for choosing among alternative options taking into consideration all costs that emerge throughout the life of an asset, from initial investment costs to subsequent maintenance and operating costs through to salvage and resale value. The DETR (Department of Environment, Transport and the Regions) Constructing Quality reports identifies whole life costing as an area of major concern (Department of the Environment 1995). It is clearly stated in the report that cheap initial costing is rarely the same as best value for money. It is the holistic picture that needs to be taken into account including life cycle costing.

This paper describes a research project which aims to add a life cycle costing element to the design phase which will allow the user within a VR environment to navigate inside the building retrieving information about building components which need replacement or repair. A colouring mechanism will be developed to show various elements in different colours according to a cost criterion. This would allow the user to easily inspect the building and retrieve information about repair and maintenance programmes, running costs and cash flows. The system will allow data to be updated continuously so that it will enable the comparison with initial plans and estimates and provides a fresh view of future action and feedback. The life cycle costing data will be incorporated into the OSCON (Open Systems for Construction) database developed at Salford to facilitate the integration of design, planning and estimating information. Like OSCON, the interface will be built around the VRML (Virtual Reality Modelling Language) standard. As VRML is a web based application, this environment will allow users based in various geographical locations to interact with the same model and retrieve relevant information (Aouad et al 1997a, 1997b, 1997c, 1997d). The user can fly through the proposed model retrieving information about maintenance and operation costs at specific points in time.

2 Life cycle costing

2.1 The concept

The *British Standard Glossary of Maintenance Management Terms in Terotechnology* defines Life Cycle Costing as:

> *" The technique of considering the total cost of ownership of an item of material, taking into account all the costs of acquisition, personnel training, modification and disposal, for the purpose of making decisions on new or changed requirements and as a control mechanism in service, for existing and future items"*

The primary objective of LCC is to evaluate and optimise a building's life cycle costs and provide a means to aid the decision making process in all phases of the building's life. Some examples are shown below (BS5760, Flanagan & Norman 1983, 1987):

- Evaluation and comparison of alternative design approaches
- Assessment of economic viability of projects/products;
- Identification of cost drivers and cost effective improvements;
- Evaluation and comparison of alternative strategies for product use, operation, test, inspection, maintenance, etc.;
- Evaluation and comparison of different approaches for replacement, rehabilitation/life extension or retirement of ageing facilities;

In short, life cycle costing is the technique of considering the initial and subsequent running costs of an asset over its planned life. The concept is not new, yet under used in the construction industry (Bull 1993). Nevertheless, the need and desire to implement life cycle costing was much talked about but little practised. This can be attributed to a number of major obstacles which can be classified under the following two categories:

1. Managerial:
   - Failure of designers to be able to visualise and include life cycle cost goals in their design criteria,
   - Failure of owners or managers with short-term responsibility for an asset to consider effectively the longer-term impact of their decisions on the asset's operations and maintenance requirements, and
   - General desires to minimise the initial expenditures in order to increase return on investment, meet budgetary restrictions, or both'.

2. Technical:
   - Lack of data, application, evaluation and feedback.
   - Absence of a database and systematic approach to collect and analyse the significant amount of information and knowledge generated over the life span of projects.
   - Assumptions, which have to be made, for future expectations, cost estimates and predictions.

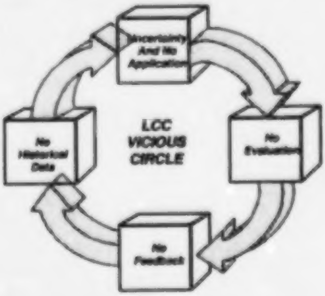

Fig. 1: Life cycle costing application vicious circle

Figure 1 shows the vicious circle in which LCC analysis is still entrapped. Any attempt to achieve meaningful analysis in LCC must provide a complete picture of a project from the initial conceptual stage until abandonment. This research project aims to provide the means to break into this vicious circle and start life into the improvement loop.

2.2 LCC and the building life cycle phases

Figure 2 shows the main phases of a complete building life cycle. It clearly indicates the potential benefits of applying LCC at the very early phases of the building's life. It is fundamental, therefore, to have a basic understanding of the activities that take place during the early phases of the project and the factors that determine their relationship to the building's performance, safety, operability, maintainability and other characteristics influencing the overall life cycle costs. Figure 2 also shows the extent that OSCON currently covers of the building life cycle and the proposed approach involving life cycle costing.

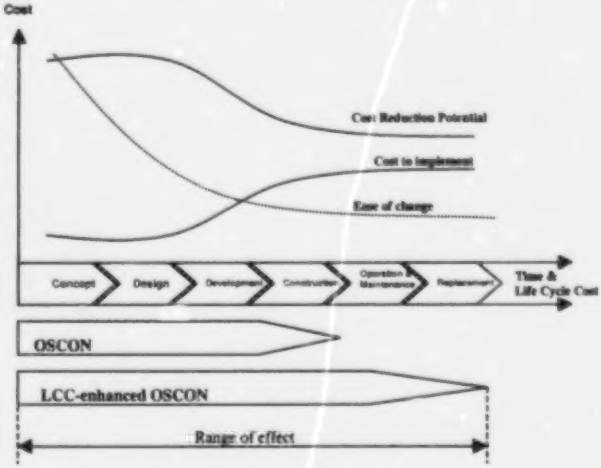

Fig. 2: Project life cycle phases and OSCON application

In order to be able to influence the uncertain relationships between present and future costs there is an urgent need to designate a clear and simple way for LCC analysis. It is also recognised that this concept will lead to major cultural changes in the approach to project investment decision making in the industry.

Assets, in general, have significant costs associated with their operation or use. These costs can add up to a large part of running expenses. A decision based on capital costs only often turns out to be more costly when the full life-cycle costs are considered. A study undertaken on three types of buildings demonstrated that a small number of cost elements consistently represent a high proportion of the total operating and maintenance costs (Al-Hajj, 1991). A further study conducted on schools in the Grampian Region has shown similar results. (Al-Hajj, 1996)

Figure 3 shows the framework of the LCC model that will be developed for integration into the OSCON system. In this model, LCC is calculated at two different levels. The first level focuses at individual elements in the building since each element is expected to have a full life cycle of its own. Thus, the model will include all costs incurring over the planned life including initial capital cost and subsequent maintenance and operation costs. The second level is at the building or asset level involving the analysis of the overall performance of the building. This includes items such energy consumption, management, cleaning, rates and insurance. At this stage the project is formatting the LCC model for the first stage.

The resulting system will obviously be, as good as the original data allows. Effective decision-making based on life cycle costing is possible only if the data input to the analytical process is sufficiently reliable. Figure 3 also shows the type of information to be collected and gives the indication that data will be gathered from a variety of sources. The system will involve gathering information on running costs and performance of occupied buildings, the identification of actual costs incurred in operating buildings and feedback to design team. The LCC model through its management system intends to monitor the performance of an asset and provide feedback. It further provides information on asset lives, reliability factors and establishes maintenance policy.

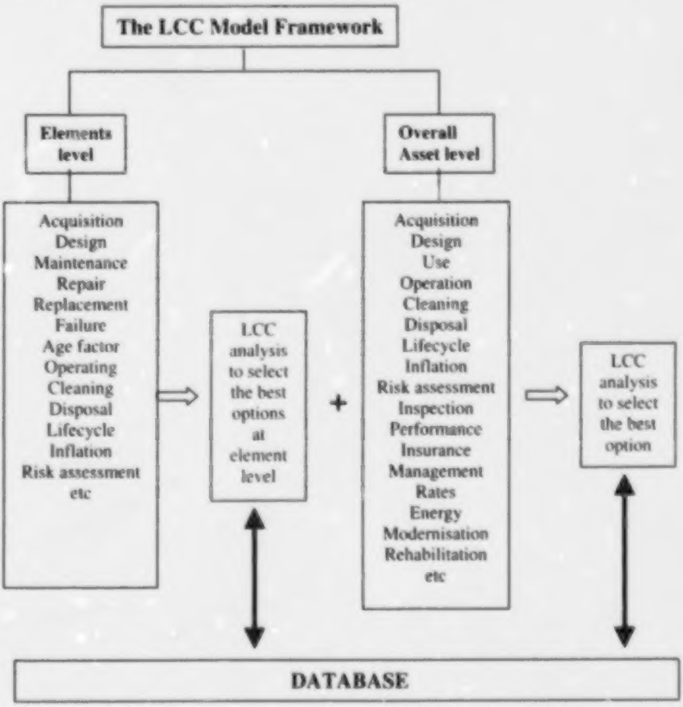

Fig. 3: The LCC framework

3 The proposed system

Studies on LCC will involve an extensive data gathering exercise even if performed for specific purposes. Computer aided systems will play a substantial role towards the efficient application of the technique considering the amount of information that needs to be taken into consideration when conducting LCC analysis. The role of information technology is becoming increasingly recognised for LCC as access to information is becoming universally viable through the internet.

Technology, particularly integrated databases and VR (Virtual Reality), can provide the mechanism to facilitate the integration of the whole life cost information. This can be achieved using the OSCON integrated database. OSCON, the Open Systems for Construction project, is a suite of integrated software that includes CAD application, cost estimating and planning, wrapper software for CA-Superproject, and a VRML interface applications (Aouad et al 1997). The system is developed at Salford University with the aim to ease and actively share construction information via a central object orientated project database. The integrated database within OSCON supports the functions of design, estimating and planning by allowing these phases to effectively share information dynamically and intelligently. The system revolves around a central object-oriented information model which consists of domain models which support integration of information within a specific domain, e.g. estimating. All the models in the system are fully independent of specific applications, and each domain model provides support for general classes of a given application. The CAD application allows a user to create and manipulate architectural components of a building. The components are stored as instances of classes in the object oriented database. These instances are read by the VRML interface in order to create a 3D view of the building which gives the user a better environment for navigation and walkthrough. Time and cost estimates are also generated automatically based on the design information stored in the database. The proposed approach is shown in Figure 4 below.

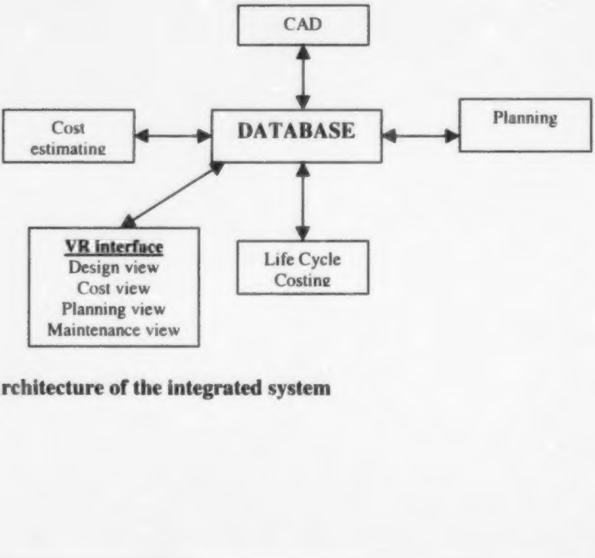

Fig. 4: Architecture of the integrated system

The proposed model will ensure that a holistic picture of the integrated project model is achieved through the support of design, planning, estimating and maintenance. The user will be able to interact with the model in real time using VR capabilities. A visual representation of the model is particularly useful for retrieving information about the maintenance phase.

As instances of design components are stored in the object oriented database, attributes related to life cycle costing will be populated. The information can then be displayed in the virtual reality environment using VRML capabilities. A maintenance view will be added to help the end user visits the model in time retrieving design and maintenance data as well as cost estimating and planning information.

4 Conclusions

This paper presented an approach to the integration of design, construction and maintenance data. The proposed model uses the state of art technologies, namely Virtual Reality (VR) and object orientation. The life cycle costing model will ensure that design is given a holistic picture that will result in better management of facilities. Life cycle costing information once inserted into the design model will allow a clearer picture of the maintenance data to be displayed in a VR environment. The system is still under development. However, once it is fully developed it will offer many opportunities for maintenance and cost engineers.

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277 PROPERTIES OF THE VIRTUAL BUILDING

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Abstract

The paper discusses properties of future digital Virtual Buildings from the client, design, construction and operation and maintenance perspectives. In this context the author defines a Virtual Building as "a formalized digital description of an existing or planned building which can be used to fully simulate and communicate the behavior of the real building in its expected contexts".

The paper focuses on: (1) requirements formulations of future Virtual Building models, (2) the necessity and possibilities to build redundant, overlapping descriptions of buildings and (3) why and how formal temporal building process properties may be included in the descriptions. The author believes that it is not possible or desirable to create a single non-redundant model to represent a building from concept to demolition. In this discussion an account is also taken of the influences of meta level information models, dependencies between multimedia presentation and application model views, the introduction of platform-independent Internet-based solutions, and the IT-support tools in future intelligent and responsive buildings.

Keywords: virtual building, modelling, multimedia, meta classification, temporal data

1 Introduction

Introduction of IT-tools into all aspects of the building process has been going on for a few decades now. IT integration is becoming a more important issue in the building industry (i.e. integration of design/construction/usage/maintenance activities and documentation within and between projects) and it serves to enhance team collaboration, to facilitate partnership and virtual organization formations, etc. Society has also seen during the last decades how 'programming languages' have developed into new generations, 1st, 2nd, 3rd, 4th, and 5th; with the main purpose of bringing the end user closer to direct

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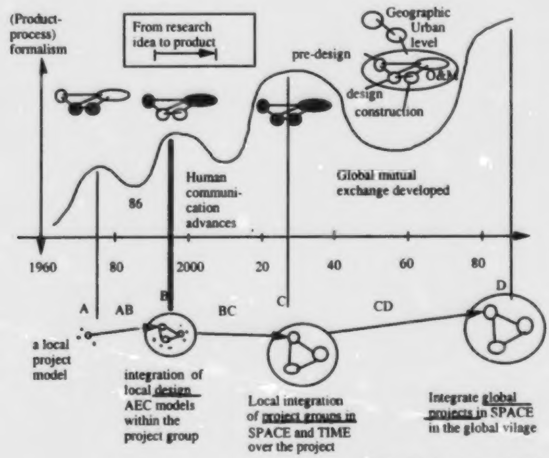
manipulation of the application models and making systems easier to build and maintain. The ultimate goal of these efforts is a virtual reality environment where designers create, directly manipulate, and test the end building products in their 'real' contexts. A supplementary historic recapitulation of building modelling trends and intelligent buildings is shown in Figure 1 given below.

2 Climbing the abstraction ladder


(Product-process) formalism
From research idea to product
Geographic
Urban level
pre-design
O&M
design
construction
86
Human communi-cation advances
Global mutual exchange developed
1960
80
2000
20
40
60
80
A
AB
B
BC
C
CD
D
a local project model
integration of local design AEC models within the project group
Local integration of project groups in SPACE and TIME over the project
Integrate global projects in SPACE in the global vilage

©Per Christiansson, 1994

Fig. 1: The formalized descriptions of the building process oscillates to higher formalism levels (Christiansson, 1994)

The building industry has now been engaged for 40 years in building formalized digital descriptions (models) of the process, and particularly of the building itself. Figure 1 (Christiansson, 1994) outlines the development so far and also tries to provide a forecast.

- Integrating building parts to a Product Model, (1970),
- User tools perspective. 3D modelling (1975),
- Cad database integration (1980). Disintegrate physically in networks (1980). Object orientation starts (1985). CIB W78 conference in Lund 'Conceptual modelling of buildings' (1988)
- Integrate mixed representations. Knowledge bases (1990). Integrate networks on services level ISDN (1990), INTERNET accelerates. Process modelling (1990)
- Connectionist product/process models (2000), everywhere accessible DKN [Dynamic Knowledge Net today World Wide Web] (2000).
What next?

- Unlearn, virtual agents, pattern communication, (20XX)..

Communication history:

- 70s (end) IGES. USA Initial Graphics Exchange Specification (1979),
- 1983 IGES/PDES. USA Product Data Exchange Specification/using step ISO/STEP Standard for Exchange of Product Model Data,
- 1988 PDES/STEP General AEC Reference Model,
- IGES 5.0 only available communication standard.

During the last 5 years (i.e. roughly 2 'Internet years') considerable standardization efforts have made progress. The industry now has the ISO DIS 13567 Layers in CAD (Björk et.al., 1997), Industry Foundation Classes, IFC 1.5.1 (IAI, 1998), and the STEP standard, ISO-10303 (ISO, 1998).

The industry must also take into consideration other supporting communication (de facto) standards such as EDIFACT, VRML (Virtual Reality Markup Language), PDF (Portable Document Format), QTVR (QuickTime Virtual Reality), Resource Description Framework, RDF, and eXtensible Markup Language, XML, (RDF, 1998). See also (Whatis?com™, 1999).

3 What's new?

3.1 The virtual building concept

Information technology will have a great impact on how the industry will design, construct and use both new and existing buildings in the times to come. The enabling technologies, described above have made great progress in several closely related fields. This will lead to changes in the following building application related areas (see also Figure 2).

- Not one non-redundant model, but *overlapping representations* of building products and processes
- *multimedia interfaces* with realistic access to underlying models
- efficient utilization of personal competencies through *computer supported team collaboration*
- efficient, interactive *building documentation*
- increased possibilities for *project experience* capture and re-use
- introduction of *intelligent and responsive buildings* in practice

The main enabling information technologies are

- efficient *access* tools to physical computer networks
- standards/protocols for *services* on the Internet
- emerging *object oriented* distributed global operating systems
- *multimedia* (this includes virtual reality) interfaces in networked environments
- use of mixed and extended *knowledge representations* in networked environments
- reliable, cost effective and high capacity *information storage devices*.

3.2 Virtual building definition

In this section the author introduces the Virtual Building definition, (Christiansson, 1993): "a formalized digital description of an existing or planned building which can be used to fully simulate and communicate the behavior of the real building in its expected contexts". IT tools can in this connection be used to:

- *design, build and use* the virtual building
- *interact* with the digital building model from idea to demolition
- *simulate the behavior* of the final building during erection, use and demolition
- check the *performance* against requirements on the final building
- support various *building processes* (from idea to demolition)

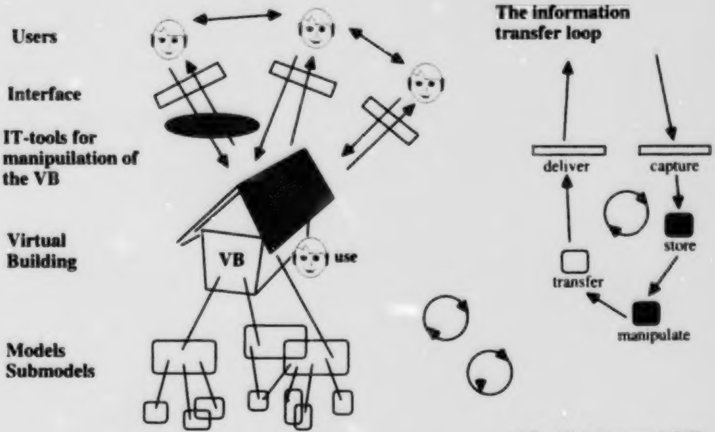


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Fig. 2: The virtual building and its sub models are accessed through multimedia interfaces with different degree of realism and provisions for collaboration

3.3 Performance of the final product : Responsive buildings

During the latest 20 years, IT has been introduced to make the buildings more intelligent and responsive to external loads, for example, weather, fire, energy requirement variations, change of use, protection, communication. Today the industry talks about intelligent and responsive buildings, though the concept is not new according to the short history account given below.

- 1982. AT&T creates the concept 'Intelligent Buildings' from marketing considerations. The Informart building with available technique is set up in Dallas.
- 1984-1985 New concepts discussed in the USA, 'Automated Buildings', 'High Tech Buildings', Shared Tenants Services' STS, and 'Smart Houses'.

- In 1986 a national Intelligent Building Workshop at Lund University was hosted (Christiansson, 1987) where some problem areas were listed: environmental issues, competencies needs, information vulnerability, flexibility demands, lack of holistic views, new contracting and procurement forms, lack of communication standards for installations systems, etc.

During the ten years after the mid 80s, not so much happened in practice. R&D projects where undertaken which lead to the development of communication standards like the LonTalk Communications Protocol (http://www.echelon.com), European Installation Bus (EIB) (http://www.eiba.com), and new standards for wireless networking (Jonsson, 1998). Now the industry can await an accelerated interest in utilizing the benefits of intelligent and responsive buildings for user services, building operation and maintenance, and interaction with services in the digital city. It is the author's view that VB will be of great importance to facilitate design and to simulate the behavior of the intelligent and responsive buildings.

3.4 The design process

It is envisioned that the Virtual Building, VB, will be used ('time') and regenerated ('t_{gen}', see figure 3) at different time points during design and will contain information about the final building product on certain detail levels, ('level'), and for alternative solutions/versions, ('alt'). As design progresses the instantiated solutions may be studied with respect to time for erection, use and demolition of the design artifact i.e. VB(time, t_{gen}, level, alt)=performance), as shown in Figure 3.

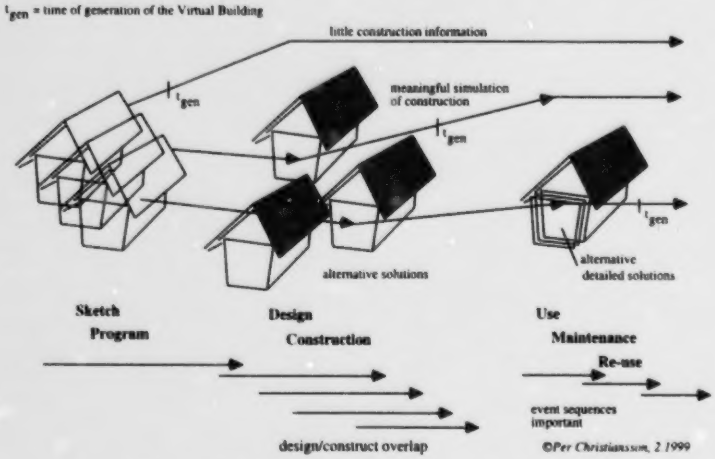
t_{gen} = time of generation of the Virtual Building
little construction information
t_{gen}
meaningful simulation of construction
t_{gen}
t_{gen}
alternative solutions
alternative detailed solutions
Sketch
Program
Design
Construction
Use
Maintenance
Re-use
event sequences important
design/construct overlap
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Fig. 3: The Virtual Building can be used to simulate all phases of the life time of a building as well as give input values to new projects

Figure 4 outlines the complex situation during the instantiation of the Virtual Building model. The functional requirements displayed in Figure 4 will influence the design of the different systems in the final building, as well as how these are related and coupled. In Figure 4, requirements are translated to functional requirements which in the design process lead to instantiated design parameters which lead to new functional requirements etc. Complex time dependent functional couplings will arise. Engineers and architects must design systems to ensure load carrying capacity, sufficient space separation, adequate supply systems (water, electricity, information, heating, communication control, etc.), as well as providing functional transportation systems, security systems, systems to guarantee comfort, and facility and property management systems, to name a few. The same VB must also be able to support different design paradigms which can be classified as creative, innovative or routine (Gero and Maher, 1993).

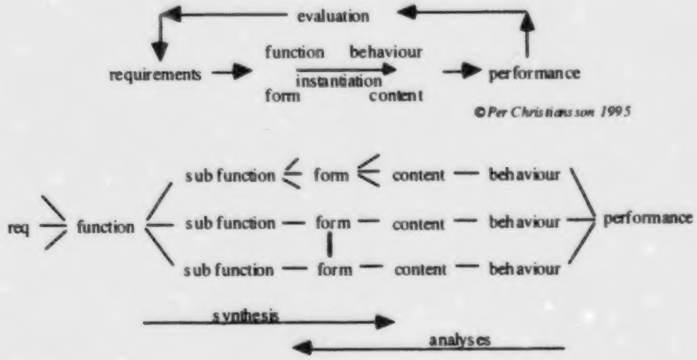

Fig. 4: The design process cycle

3.5 Handling redundancy in the virtual building.

The degree and type of redundancy in the Virtual Building model depends on factors such as type of project, organizational environments, design culture, and stage of development of the VB model. In case of a very standardized type of product there will be little need to handle redundant information.

In Merriam (1993) the following definitions are found:

- *Redundant* - (1a)" exceeding what is necessary or normal"
- *Inconsistent* - (a)" not compatible with another fact or claim, (b) ... containing incompatible elements"
- *System* - (1)" a regularly interacting or interdependent group of items forming a unified whole. (3)... An organized set of doctrines, ideas, or principles usually intended to explain the arrangement or working of a systematic whole."

The envisioned VB of the future will give building designers and users many opportunities to handle redundant information which may be very beneficial. It will be able store alternative solutions to ensure that inconsistency will not arise between forms/contents during fulfillment of functional requirements (e.g. installation clashes, steel and wooden door).

Powerful computers of the future will allow designers to rebuild the building on the fly, as many times as *desired*. During this simulated building process checks can be made for inconsistency in the derived solutions and the solutions development processes. In order to narrow an expanding solution space, designers and users must introduce decision points after which sub designs are fixed. Further, warnings can be given for manual interaction if the solutions are undersized (e.g. no ventilation ducts sketched, which causes the fire protection system to be undefined with regard to possible fire spread, or prompt the responsible persons to check buildabilty with regard to dynamic effects on neighboring structures). In the future, helpers, in the form of software agents may be developed and introduced in the VB to prompt the building process participants during consistency checks.

Other recent papers relating to redundant data (Christiansson, 1998) describe how hypertext (with redundant information) can be meta structured using RDF (RDF, 1998), enabling efficient indexed meta level cross search in documents contents, and describe efforts in the European Esprit Condor project to model semantic linking between different Electronic Document Management, EDM (Rezgui and Cooper, 1998).

4 Virtual building in context

4.1 Environmental loads

The Virtual Building will exist in a context defined by

- Geographical and sociological *location* of the real building project.
- Building project *participants*.
- Digital *information environment* (past experiences, external product data, etc.)
- Application *software environment*.
- Computer *hardware* and *operating systems* environment.
- Computer *communication* services protocols.
- Computer *physical* network environment.

The environment affecting a building presents external loads of different kinds on the VB (i.e. loads from weather, city resources supply systems, sunlight access, etc.), as does the usage of the building (i.e. change in utilization, user comfort profiles, user services and maintenance demands). One external load, 'access load', rarely considered, is derived from the fact that digital data has a limited access life time, as shown in Figure 5.

Practitioners will also need to develop support systems to interpret digital data (for example, pattern recognition IT).

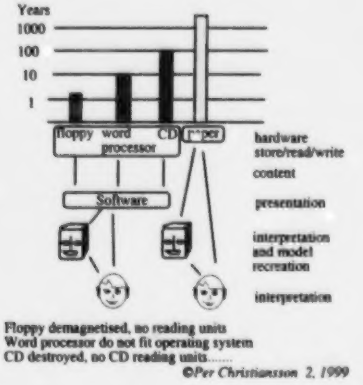
Years
1000
100
10
1
floppy
word processor
CD
paper
Software
hardware store/read/write
content
presentation
interpretation and model recreation
interpretation
Floppy demagnetised, no reading units
Word processor do not fit operating system
CD destroyed, no CD reading units.......
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Fig. 5: Digital data media has limited access life time and must continuously be renewed

The Building Process is composed of sub processes which may be well formalized (in production lines) in the case of manufacturing of supply or building components. Practitioners of the future may, in connection with 'industrialized individual building', develop a closer interaction between the more unique once-in-a-lifetime building project and the static linked supply processes (information and products on demand). An example of this is provided in Figure 6. In the SERFIN system (Technical Building Maintenance on the Internet) meta structured information can be searched through Building Part, Material, Problem type, Environment and Action vocabularies and/or pure free text. (Christiansson, 1997).

4.2 Temporal Aspects of Data

In the future, industry will have greater possibilities to handle temporal data in databases since e.g. temporal extensions to SQL (Structured Query Language for relational databases) which now, after 25 years of evolution of SQL, are beginning to be implemented (Snodgrass, 1994). This means that users can add time dependent data to the databases and do searches where they can handle both point-based and interval-based temporal data. A temporal SQL is proposed which has similar syntax as and is backward compatible to standard SQL (Böhlen and Jensen, 1997).

With temporal data introduced into the VB, new opportunities arises:

- we can store snapshots of different building processes and *backtrack* to make a re-design or re-simulation with changed requirements (regeneration of the VB),
- it should be easier to document and retrieve *causal connections* over *time* and *space* in the VB,
- storage of *lines of reasoning* and possibilities for analyses of their relations
- effective use of the time parameters in the *life time documentation* of building behavior

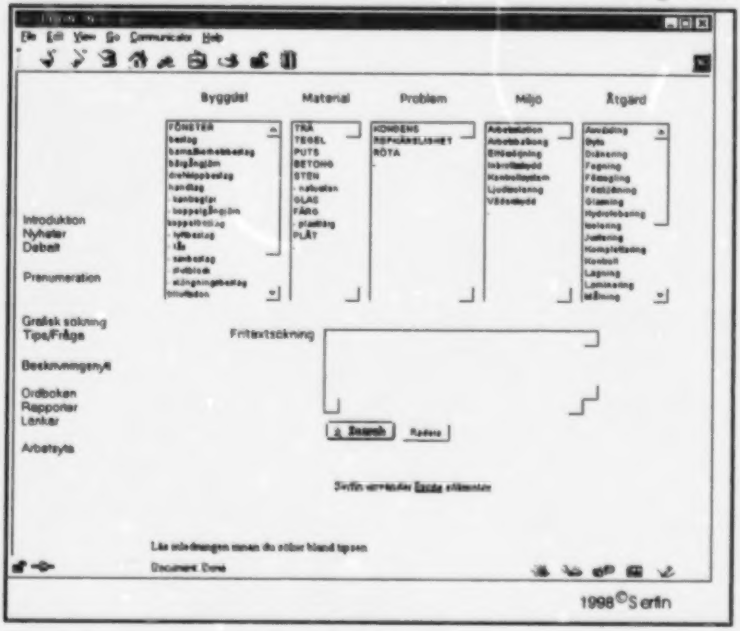

Fig. 6: The digital VB information environment has to be documented

4.3 Virtual building universe of discourse

The industry will be receiving more powerful IT-tools to store and handle the Virtual Building. How much shall be stored? For example, if one makes a reference to a regulation should the system store that part of the regulation? Can we guarantee that it will be easily available in the future? Shall one also store the terms/classification and definitions/dictionaries used? Please refer to Figure 5 and (Burns and Cole, 1998).

How much of the context shall be stored in the VB itself? These are not easy questions to answer, as they are highly related to the cost of building a self contained VB; i.e. who invests in, owns and will benefit by a comprehensive VB?

In general building practitioners will see new services develop which will act as *secure information containers* for long term digital information on *project level* that lies below the more secure global library information storage with its long (centuries) validity. (A project in this context contains *all* organized undertakings). The author's suggestion is that practitioners should store more rather than less information, until the knowledge communication society has stabilized (50-100 years).

4.4 The virtual building as a shared workspace

The VB and its multimedia interfaces will greatly enhance and influence the communication and collaboration support among the involved building process participants who have different working styles, competencies and personalities.

The VB users' interfaces have a crucial influence on:

- degree of *realism* in access of the Virtual Building
- *efficiency* in navigation, search and manipulation of the VB
- how well *collaborative* work on the VB will be supported

It would be, at this time, too premature to further elaborate on the influence of assumed and implemented user models which the VB will support. To determine this, it will be of great importance to take into account many factors such as different building process participants background, competencies, and modes of intelligence. In addition to Howard Gardners seven or more modes of Intelligence, (Gardner, 1993), the emotional intelligence, (Coleman, 1997), will play a more vital role in the design of the user models contained in the versatile future VB.

5 Conclusions

The paper discusses the future properties of the virtual building, here defined as "a formalized digital description of an existing or planned building which can be used to fully simulate and communicate the behavior of the real building in its expected contexts". It is a continuos endeavor to develop end and refine the Virtual Building and the industry will constantly have to make re-assessments. It is now time to do some creative, bold, and holistic inceptions at both universities and industries and as well as collaboration between them, both to construct and evaluate models of Virtual Buildings for the benefit of the end-users of the buildings and the building industry itself.

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278 THE VIRTUAL BUILDING — THE IMPLICATIONS OF ITS PREPARATION DURING THE DESIGN PROCESS

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Abstract

This paper examines the impact of the preparation of the virtual building as an outcome of the design process. The implications for the design practitioner working in an environment in which a virtual building model is prepared and tested prior to commencement of construction are discussed. Changes to the current organisational structure of the design process are suggested if a move is to be made toward an integrated virtual building construction and performance modeling environment.

Keywords: Virtual building, design process, communications, integration

1 Introduction

Traditional methods of project procurement in the building industry are based on a clear separation of the design from the construction process. This occurred during the eighteenth century when the diversity of skills and technical complexity of construction became too great for the craftsman to carry out both design and construction as had been done previously (Saint 1983). Architects then emerged from two discipline areas. One from the arts based amateur designers and the others from at least a background in the building trades. The development of the art - architecture as a distinct profession was based on the exclusion of '…surveyors, measurers and those with interests in the building trades…' (Saint 1983, p.61). The legacy of this foundation is evident throughout the development of the RIBA and the maintenance of the current separation of the architect as designer and the master builder as the contractor. This separation of design from construction or manufacture has also been the focus of other manufacturing industries since the development of mass production after the industrial revolution (e.g. Womack et al. 1990).

Durability of Building Materials and Components 8 (Volume Four). *Edited by M.A. Lacasse and D.J. Vanier.*
Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17743-9

The recent reevaluation of the relationship between design, manufacturing, product quality and lifecycle has lead to the development of the concept of concurrent engineering. This is the '...systematic approach to the integrated, concurrent design of products and their related processes including manufacture and support' (Rammig and Steinmüller 1997). High levels of integration identified as being so critical to the implementation of concurrent engineering is facilitated by the use of information technology and in particular computer-aided design (CAD) (Hartley 1992). Without CAD systems and integrated performance simulation packages, the level of resolution and pre-manufacture testing of a proposed design is less likely to fulfill the promised outcome of increased product performance and quality associated with more economical and efficient manufacturing.

The construction industry has developed a system of operation which, despite the developments in information technology, has not changed significantly over recent years. This has resulted in the industry developing a reputation for poor productivity and performance. This is in contrast to other industries that have tended to view IT as at least one of the mechanisms for increasing competitiveness and product quality (e.g. Johansson 1996). While the building industry may be seen as unique in so far as it deals with one of a kind construction, there are manufacturing sectors, such as shipbuilding, which have very similar limited production run operating environments. These see the use of IT, in particular virtual performance evaluation and assembly, as a means of increasing the predictability and reliability of the outcome of one of a kind manufacturing processes (e.g. Ouillette 1994; Tatum et al. 1994; White 1990).

By more accurately forecasting both the applicability of procedures to be used in the construction process and the performance of the completed constructed object, the predicted financial commitment becomes increasingly reliable with a subsequent reduction of overall risk in undertaking a project (e.g. Bennett and Lamb 1996). Virtual building project modeling has the potential to be a mechanism for such forecasting in the construction industry.

The impact of the development and implementation of the virtual building project as part of the design process is likely to have a profound impact on the construction industry. This has the potential to significantly influence the way buildings are designed, how the design intent is communicated and the means which are used to support the construction and lifecycle maintenance process. However, the transition to this may be problematic, particularly for architectural practices.

2 Outcome of current documentation in traditional procurement

The outcome of the culmination of the design and documentation process is a set of contract documents consisting of working drawings (including those supplied by specialist consultants), specifications and a written contract. The description contained in these documents is that of an idea for a three dimensional object transformed into a two dimensional medium from which a three dimensional object is to be constructed (Figure 1). The building as a three dimensional object generally exists in the mind of the designer, although possibly not in the mind of the client (Cuff 1992), and is communicated to the builder using a two dimensional medium. There is therefore a great reliance in the experience of the designer in being able to visualise the building as a three dimensional object and then translate that vision into a two dimensional medium. As buildings become more complex in design, construction and servicing, this becomes more difficult. At its most complex, it may be impossible for any one individual to fully understand a building in its entirety.

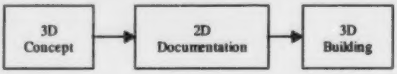

Fig. 1: Design concept transformation

2.1 Representation

The outcome of the architectural design process is a set of 2D documents which aim to communicating the design intent, but which do not fully describe the building as it is to be built. Rather, they are prepared in a shorthand language that is generally understood by the various participants in the construction industry. The interpretation of the documents is based on a set of conventions, knowledge of which is built up over years of participation in the industry. The language has been defined (Standards Association of Australia 1985), however it does not attempt to fully describe any building and simply seeks to standardise the vocabulary and interpretation of the language used. For example, the documentation prepared for Australian brick veneer construction does not show timber studs at 450mm centres although there is a clear, and universally assumed, intent that they should be placed where required (Figure 2).

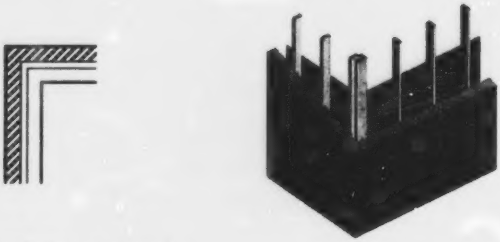

Fig. 2: Documentation vs. meaning

Detailed resolution of a design prior to finishing the documentation is therefore not required and a complete and comprehensive description of the building is not assumed to be provided (at least by the building contractor, although it may be by the client). The documentation as prepared therefore uses a graphic language that does not assume that a fully complete description of the building is even intended to be provided. It is apparent that, despite the incomplete documentation, the intent is that a complete, stable and usable building is to be constructed. Anecdotal evidence suggests that the closer a set of documents approaches a full description of the building the higher the contract price is likely to be. This is a clear disincentive to thorough documentation and, by implication, thorough resolution of the design. The apparent danger of over documentation is a factor architects appear to be conscious of. Builders do not expect a full building description nor necessarily see it as desirable as it tends to reduce the flexibility in how they undertake the construction process.

2.2 Definition of responsibility

In the preparation of the documents, the issue of responsibility arises. There is a clear definition of responsibilities during the design and construction process. Each sector of the industry attempts to ensure that they are not responsible for another's contribution over which they have little or no control or knowledge (RIBA 1991). This has a significant impact on the nature of the documentation as prepared. Each consultant, such as the structural or mechanical engineer, prepares separate documentation for their area of responsibility. Architectural drawings seek to define the overall building form and coordinate the various sets of consultant's documents (Figure 3).

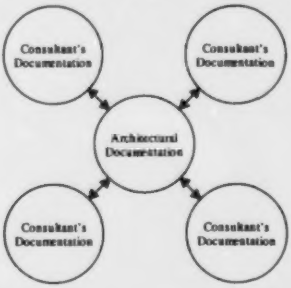
Consultant's Documentation
Consultant's Documentation
Architectural Documentation
Consultant's Documentation
Consultant's Documentation

Fig. 3: Relationship - Architectural to consultant's documentation

In the traditional method of procurement, this separation of responsibility carries through to the construction process, the details of which are determined by the contractor after design and documentation is complete and tenders are let. Not only is detailed resolution of the construction process not required during design and documentation, in the traditional form of architectural service it would be encroaching on the responsibility of the builder (RIBA 1991). It is therefore the architect's role to coordinate the preparation of a description of what is to be built not define how to build it.

This requirement for clear definition of responsibility encourages fragmentation and compartmentalisation of information that is used to describe the building that is to be constructed. The seamless integration of information in order to describe the building as a whole is therefore discouraged and information *silos* are created. This is characteristic of a sequential engineering process which has created difficulties in manufacturing and has led to the development of concurrent engineering (Prasad 1995).

2.3 Visualisation

The purpose of design visualisation is to communicate the visual and spacial quality of the design intent. However, it brings with it its own limitations related to the scope of information that is necessary to include in the building model from which the visualisation is developed. When preparing a virtual building model as a visualisation tool, two elements only are required:

- geometry of visible surfaces
- visual properties of visible surfaces (e.g. texture pattern, colour, reflectivity)

It is apparent that the amount of information embedded in a 3D model, which describes a building for this purpose, is not complete. It clearly does not approach the complexity of that which is necessary to describe a building in any comprehensive manner. In addition, the model may only require a small part of the building to be described and may be analogous to that of a movie set in which only the visible parts of the form need to be shown any concern.

The 3D model prepared for design visualisation is therefore lacking information that would make the model usable for any other purpose. Thus, it excludes information such as thickness, location and composition of subsurface materials. These have a critical impact on the overall performance of the building as a complete operational system and are necessary if any performance analysis is to be undertaken using the prepared building model. The current 3D models, which may be developed as part of the design process (Dawson 1996), require substantial additional elements, both geometric and not geometric, if they are to be utilised as anything other than a presentation or visual design evaluation tool.

3 Design within a virtual modeling environment

Design development support systems and methods of communication operating within a virtual modeling environment are under development in industries other than construction and contrast markedly with those described above. These include aircraft design (e.g. Business Week 1991), automobile manufacture (e.g. Van Niekerk 1995) and shipbuilding. Of these, shipbuilding is potentially of the most interest with limited series production (down to one of a kind) of technically complex large scale objects manufactured from simple components (Johansson 1996). Some ship designs may be likened to small cities with infrastructure including restaurants, hotels, and HVAC systems and, with the exception of hull structures and propulsion units, may be very similar to buildings in their architectural requirements.

The development of virtual design support systems is resulting from the application of concurrent engineering to ship design and construction. The shipbuilding industry, particularly in the United States, has seen the development of concurrent engineering as a means of increasing competitiveness (Bennett and Lamb 1996). Key concepts which have developed from this have been the carrying out of design, performance testing and construction process evaluation before manufacturing commences (e.g. Ouillette 1994). This has benefits in increasing the predictability of the performance of both the construction process and the completed product. That in turn reduces the financial risk associated with the design, construction and operation process.

The development of 3D CAD models as a means of validating design decisions related to complex control or machinery spaces has been carried out. This has been demonstrated to be of clear, if qualified, benefit (Tatum et al.

1994). However, this is little more than design visualisation as an alternative to constructing full scale mockups. The greatest opportunities are potentially the development of complete product models from which relevant and appropriate information can then be extracted as required.

The product information model (Figure 4) has been proposed as a single source of information to support the design development and evaluation process (Johansson 1996).

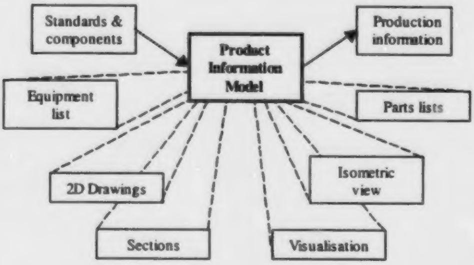

Fig. 4: The product information model (after Johansson 1996)

The model contains both geometric and non-geometric information. Stored non-geometric information includes such data as weight, surface treatment and energy consumption. In addition, it also identifies connections and dependencies between objects. Although the product model does contain geometric information and visualisations can be generated, its primary focus is on the non-geometric data. The complexity and extent of the non-geometric data is clearly recognised. With this level of embedded information, the product model becomes a rich source of data for further development of performance, construction or lifecycle maintenance simulation.

There are two key elements which facilitate the implementation and success of concurrent engineering and subsequent development of product models and virtual performance simulation in shipbuilding:

- a design/build organisational structure in which the client approaches a shipbuilder who then carries out all operations from initial briefing to completion of construction and possibly maintenance and refit. A design may be developed specifically for a client's needs or may be purchased from a naval architect and then modified by the shipbuilder's own design office.
- the continuity of organisational structure from one design/construct commission to another where long term continuous relationships are established between the players in the design and manufacturing process. These include design engineers, external suppliers and sub-contractors, shipyard workers and possibly the client.

These elements give a level of cohesiveness and stability that are not available to organisations that are fragmented and transitory.

4. Product information model for construction – the virtual building

Information models developed within the construction industry are characterised by a focus on the transfer of information between players within the industry (IAI 1997; Anumba et al. 1997) (Figure 5).

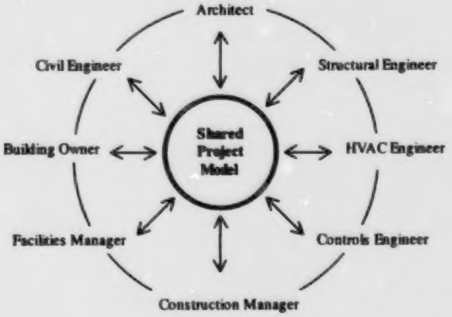

Fig. 5: The shared project model (after IAI 1997, p. 2)

For a fragmented industry, an emphasis on the seamless interchange of information is attractive. This facilitates the electronic transfer of design and construction information across multiple computer platforms and CAD systems. However, the shared information model does not necessarily lead to the level of integration that other industries perceive as being important for increasing product quality and manufacturing efficiency through virtual model development and testing of design proposals.

The level of information density contained in the virtual building model should allow the following to be carried out:

- design validation from a visual, spacial and functional perspective
- performance simulation both before, during and after completion of construction
- construction process simulation

The virtual building, which is developed based on these concepts, is required to embody the total definition of the building. It is therefore required to contain the following (Dawson 1998):

- comprehensive information about the building form and geometric relationships between assemblies of components
- geometric information about the individual components used to make up the component assemblies
- comprehensive information about the graphical and nongraphical properties of component assemblies
- comprehensive information about the logical relationships between components and component assemblies

The ability to undertake this level of testing both during and after development of a virtual built environment introduces the concept of simulation based design to the development of the virtual building.

5 Discussion and conclusions

It is apparent that the methods of building design operation, which culminate in the current contract documentation, lead to:

- incomplete resolution of the building as a three dimensional object
- incomplete resolution of the building detail as it is to be constructed
- documents used to communicate design intent being incomplete
- reliance on others in the construction process, such as contractors or sub-contractors to determine how to build a completed (although not complete) design
- fragmentation of design information across multiple disciplines
- fragmentation of responsibility where unambiguous definition of boundaries and responsibility is often difficult

This results in a focus on who wants what information rather than on what information is required in order to most economically and efficiently construct the building or its parts so that it will perform in a predetermined manner over time.

Two elements characterise the virtual building, its completeness and its homogeneity. The virtual building is prepared so that it can be analysed in a manner that replicates a set of performance experiments on an actual building. These range from analysing virtual assembly methods to determining the impact on energy consumption of alternative methods of refurbishment. In the virtual building there is no separation of element description based on responsibility. There should be no information about the design that exists solely in the mind of an architect or contractor.

The current structure of the construction industry, the particular relationship between its players and the method of communication, preclude the development of product information models or their extension, the virtual building.

The development of the virtual building requires availability of all major participants in the design and construction process from initial client contact. This ensures that the model that is being developed through the design process is complete and fully reflects what is planned to be built. Major changes are therefore necessary in the structure of the design sector of the building industry:

- designers will be required to offer clients complete packages of service from pre-design to maintenance, involving contractors and suppliers
- long term relationships need to be developed between designers, contractors and suppliers
- designers will be required to place emphasis on complete design resolution before construction commences
- designers will be required to seamlessly integrate information from various consultants into a single project information model (or its successor, the virtual building model)

Ultimately, the outcome of the design process will be the preparation and testing of the proposed design through the development of a virtual building model, not the preparation of 2D contract drawings or 3D visualisations.

Whether these are initiated by architects, as the traditional coordinators of the design process, or project managers, as suggested through the application of concurrent engineering to the design and construction process (Love et al. 1998), remains to be seen. However, it is currently not clear whether designers will be able to make the transition from their current fragmented methods of operation to one in which there is an emphasis on quality, predictability and efficiency of outcome for all concerned.

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279 LEARNING CONSTRUCTION IN VIRTUAL WORLDS

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Abstract

Virtual Reality Modeling Language (VRML) is a tool for creating and distributing virtual worlds on the Internet. It can be used to create a 3D virtual environment by computer-rendered simulation of an interactive scene with links to other virtual worlds or 2D information. It allows information to be organized spatially and related by location and proximity. This paper summarizes the concepts and potentials of VRML applications in the construction industry. The design and development of virtual worlds of building construction is discussed. User's interaction with the virtual worlds to explore and understand concepts in construction is illustrated.

Keywords: Virtual Reality Modeling Language, VRML, multimedia, hypermedia, 3D modeling, construction technology, computer-aided learning, CAL

1 Introduction

Education can be viewed as a knowledge transfer process from two different perspectives:

- Instruction: information provider (professors, tutors, and computer-mediated systems) takes an active role in presenting information to learners.
- Learning: learner takes an active role in retrieving information from external sources; analyzing and structuring the information to develop his own knowledge.

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A channel of communication is required to enable information to be represented and transferred from providers to learners. A variety of channels are currently used: books, lecture notes, videos, slides, and World Wide Web (WWW) etc.

Traditional classroom situation is an instructional process, which is teacher-centred. The process is dictated by the teacher who determines the way that information is transferred to the students. The counterpart to instructional process is an exploratory learning process, which based on student's initiation and control to dig out information relevant to his needs and interests. Library is a basic knowledge source to support the learning process.

2 WWW and computer-aided learning

Development in computer-aided instruction and learning are to improve the information transfer process. A computer-aided learning system has three basic components: learner, knowledge core, and delivery system. The development of Internet and WWW establishes a standard for the delivery system. From an instructor's point of view, WWW is a new way to deliver instruction. From a learner's point of view, WWW is a huge database for him to explore. WWW is a new medium for education, a new opportunity for learners to discuss, share and collaborate. How to represent knowledge content on the WWW to achieve learning objectives is an important area of research.

Learning is a process of active engagement with experience. Learning is sustained by mental stimulation, and encouraged by proper environment. WWW provides the basic tools to develop an exploratory interactive learning environment. Interactivity refers to activity performed by a learner in response and in relation to the learning environment. Use of appropriate media and technologies enhance the interaction between the learner and the environment. In traditional settings, learners are confined to basic "static" interaction with materials delivered through one-way media in the form of printed text, images, audio, and video. With the advent of new media and technologies, dynamic interaction is now possible and affordable. It brings the learner closer to the act of discovery, e.g. examining objects in exploration of virtual worlds. In addition to course material and contextual information, the selection and use of appropriate media and technologies becomes an essential factor for establishing and maintaining interactive learning environment.

With new technologies comes the challenge for creating new, interactive learning environments which facilities learning and promote open and constructive dissemination of knowledge. It is perhaps the turning point for new paradigms to emerge.

Hypertext was the first tool to enhance interactivity on the WWW. It broke down the traditional linear nature of the written word by encouraging readers to find their own paths through large amounts of information with embedded links. With the advent of digital technologies, hypermedia emerged to include text, images, audio, video, and animation as information nodes.

3 Virtual reality

In construction industry, three-dimensional (3D) information is essential. In traditional communication media, 3D information is represented in a two-dimensional (2D) format such as drawings and photographs. Sometimes, physical models are constructed using cardboard so as to examine the form, shape, or spatial relationship between various elements. With the advancement in computing technology, computer generated 3D models can now be built instead of physical models.

Virtual reality (VR) is a computer-generated simulation of a 3D environment, in which the user is able to both view and manipulate the contents of that environment. Usually it is associated with an immersed experience that requires special-purpose hardware such as head-mounted display and data gloves. VR is a computer system used to create an artificial world in which the user has the impression of being in that world and with the ability to navigate through the world and manipulate objects in the world. Current technologies are not only able to provide a visual experience, but also with 3D sound, touch and force, for users to explore. The CIB established TG 24 to study and document the existing Virtual Reality efforts in construction. The applications of Virtual Reality studied include those in Building Design; Facilities Management; Real Estate; and Promotional Sales.

There are other ways of implementing VR without special gear to cut down the cost and to distribute and share virtual worlds on Internet.

4 VRML and construction

VRML is an abbreviation for Virtual Reality Modeling Language. The VRML Consortium is a nonprofit corporation founded in 1996 to provide a forum for the creation of open standards for VRML specifications. It established an open standard for creating and distributing 3D multimedia and shared virtual worlds on the Internet. VRML is a scene description language that describes the geometry and behaviour of a 3D scene. It is a 3D graphics standard, representing a platform-independent multimedia file format for delivering interactive virtual worlds. The user just needs a VRML browser, similar to WWW browsers, to visit and navigate VRML worlds. Using VRML, 3D models, video, graphics, audio and text presentations can be integrated into a single virtual world, which makes communication easier and more powerful.

Virtual worlds can range from simple objects to very complex scenes. Background colours, textures, lights, sound, movie, and animations can be used to enrich the virtual worlds. Sensors and scripts are used to define user interaction and objects' behaviours. User can fly through, walk through, examine, and explore in virtual worlds. User can interact with objects or even another user in virtual worlds.

Traditional textbooks of building construction make use of drawings to illustrate the concepts. Training in understanding drawings enable students to visualize the concepts in a 3D manner. To get a better understanding of the concepts, students need to relate them back to the real world situation by referring to physical samples and site visits.

Construction drawings describe each building by floor plans and sections. Each floor plan shows interconnected rooms, position of doors, windows, and staircases. Symbols are used to define whether a door opens inward or outward and whether a staircase goes up or down. VRML directly reflects this hierarchical decomposition with separate elements for rooms, floors, walls, and ceilings. Additional attributes define the appearance such as colour of the walls and ceilings. Room fittings such as tables and chairs can be described by reference to external 3D models.

There are two essential elements in VRML to enrich virtual worlds and to add behaviours to objects: anchors and sensors. Anchors are used to create hypermedia links that represent a logical, spatial, or hierarchical relationship. Anchors allow user to interactively recall and view linked information by selecting objects of interest during navigation. Linked information can be another WWW page or another virtual world. A rich data structure that allows for extensive cross-referencing can be created. Sensors are nodes in the virtual world that react to users' actions such as touch or drag an object. Objects' behaviours can be activated according to the user's interaction with the sensors.

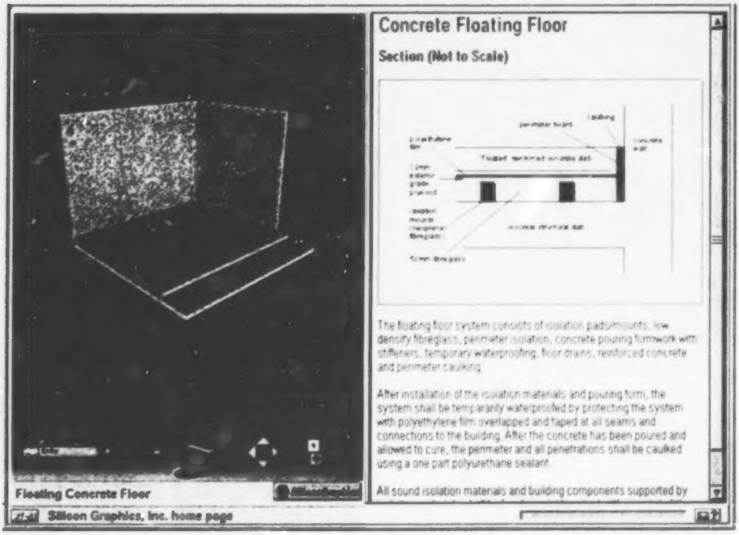
For example, user entering a virtual room sees the floor, walls, ceiling, windows and doors. User can move around in the room to explore. Selecting the door can bring up another virtual world showing detail elements of the door. Selecting the elements may start an animation that shows the assembly sequence of the door. It may also bring up another web page showing construction detail drawings, specifications, and costs. For building elements that are not easily observable such as air conditioning systems, exploration in the virtual world makes the user easier to understand the components and their relationships. A virtual air conditioning system includes chillers, fan coil units, ducts and pipes connecting components in a 3D space. Selecting each component may show a more detail model of the component.

5 VRML applications in construction

The construction industry can use VRML to explore exact representations of architectural drawings and models during the design stage. Design team members can communicate with 3D models in addition to drawings. The virtual building representation can be augmented by linking to its various components, the original drawings showing construction details, photographs of the real site, and so on. The interactive 3D models can therefore be used for data management purposes. Information about the building can be presented and communicated with maximum efficiency. Figure 1 is an example showing a virtual world of concrete floating floor augmented with drawing and text. The real estate industry can show flats in VRML on the Internet to clients, allowing people to get a feel for physical space. Suppliers can have 3D catalogs of their product on the Internet for demonstration. Assembly of complex parts is better communicated through 3D interaction. Figure 2 shows a sample design of office furniture. In education, virtual worlds can be use to illustrate the construction details and processes. User can select the angle of view and can interact with objects at his own pace.

6 Learning in virtual worlds

Virtual worlds provide a basis for exploratory learning and can be used as an educational tools for promoting non-linear thought. It also allows the users to have some degree of control over the learning environment and to adapt materials to their own learning style. Another learning approach is to have students creating their own virtual worlds. Students can gain hands on experience in a simulated construction process. Since components are reusable, virtual worlds can easily be built by selecting appropriate objects from standard libraries. Figure 3 and 4 show some objects from standard library for building construction. Students can organize, structure, and associate objects in the virtual worlds in their own way. Their virtual worlds reflect their understanding of the concepts and knowledge in construction.



Concrete Floating Floor

Section (Not to Scale)

The floating floor system consists of isolation pads/mounts, low density fibreglass, perimeter isolation, concrete pouring formwork with stiffeners, temporary waterproofing, floor drains, reinforced concrete and perimeter caulking.

After installation of the isolation materials and pouring form, the system shall be temparanly waterproofed by protecting the system with polyethylene film overlapped and taped at all seams and connections to the building. After the concrete has been poured and allowed to cure, the perimeter and all penetrations shall be caulked using a one part polyurethane sealant.

All sound isolation materials and building components supported by

Fig. 1: Virtual world of concrete floating floor augmented with drawing and text

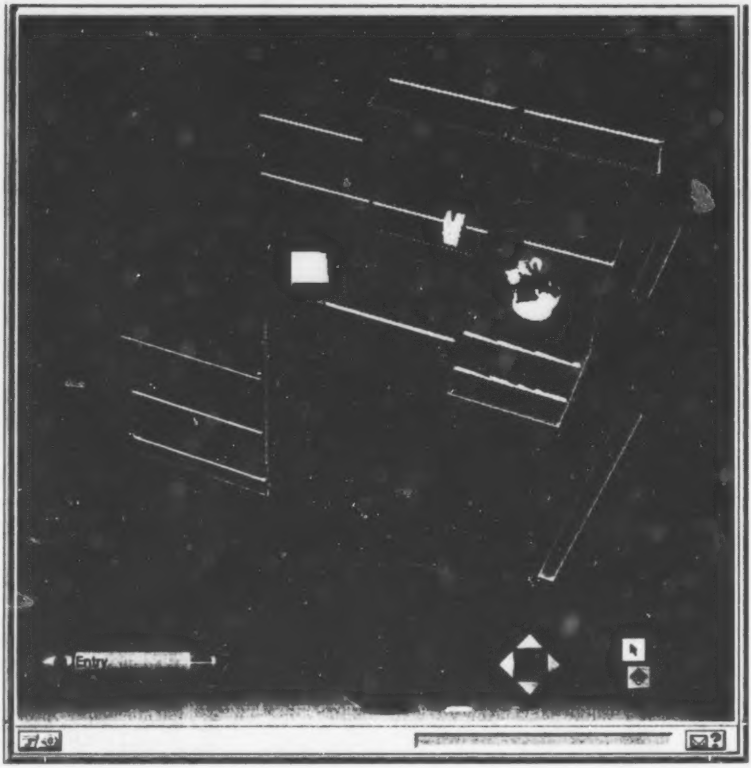


Fig. 2: Sample design of office furniture

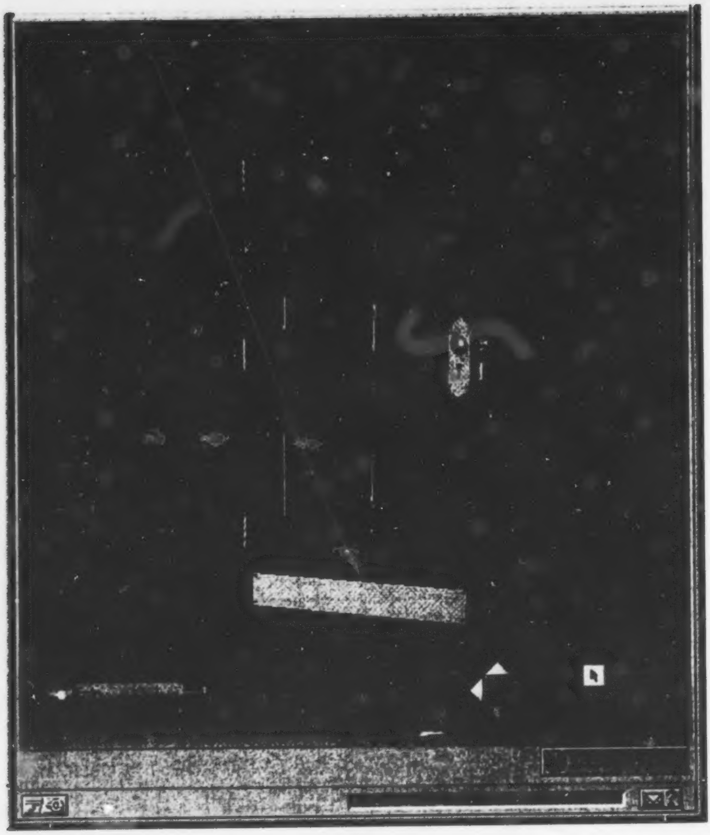


Fig. 3: Standard component: oak door

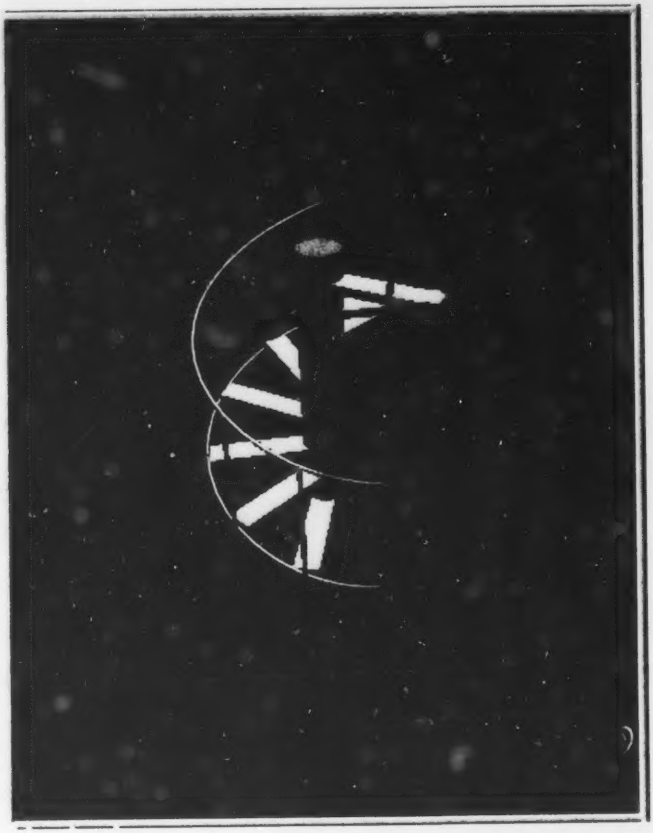


Fig. 4: Standard components: spiral stair

7 Future development

Today's virtual worlds on the web are still largely exploratory in nature. Many authors, range from universities to businesses to individuals, are still learning VRML as a new medium. Current VRML standard still lacks some important features of interactive 3D world, such as shared object behaviours and cause-and-effect relationships. The VRML standard is continuing to evolve to include more complex notions, such as objects that change over time. This will allow even more compelling applications to be created.

The creation of a distributed multi-user virtual world is another research area. When a user enters a virtual world, there is actually an embodiment of the user in the world, known as an avatar. So different users, represented as different avatars, can interact with each other in virtual worlds at the same time to form a virtual community to share, discuss, and collaborate. The potential of such an interactive learning environment is still waiting to be explored.

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280 VIRTUAL CONSTRUCTION FOR AUTOMATED SCHEDULE GENERATION

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Abstract

Ongoing research in automated schedule generation does not allow for interactive user input sessions to translate design information required for sequencing project activities. Rather, current research has focused on capturing, among other things, design knowledge through interpreting 2D drawings and/or 3D CAD models to develop intelligent schedule generation tools. Further, many of these tools do not address the importance of schedule development during the design phase. In this paper the authors introduce "virtual construction" sessions for re-assembling of 3D CAD models in a virtual environment. This will allow for capturing and recording user input for automatic generation of project schedules.

Keywords: planning, scheduling, virtual construction, 3D CAD, 4D planning, constructability, design, construction

1 Introduction

Schedule generation is an important part of the construction planning process. Scheduling is generally carried out several times during the life of a construction project from preliminary schedules at the project feasibility phase to detailed short interval schedules during field construction. Most planning efforts in construction use the schedule and the design documents as the primary planning tools supported by estimating packages and other aids.

The work carried out at the Center for Integrated Facility Engineering at Stanford has demonstrated the benefits of using 4D (time and space) models in

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visually demonstrating the progress of the field construction stage of the project (see for example McKinney Liston et al, 1998). The Stanford researchers have identified that the current 4D CAD tools are useful to communicate the overall sequence of construction, but generally do not provide enough information for construction planners. In our opinion this problem arises from the way that the schedule, the time part of the 4D model, is developed. The schedule is a sequencing document that defines when construction activities will occur and may also provide information on when resources, materials and previously completed work will be utilized. There is no information, in the schedule, on the method that the designer, estimator or construction planner envisaged would be used to perform the work. In fact it is not unusual for the designer to give little consideration to the construction method in coming up with an overall schedule for the project. Such issues are left for determination later in the process. This results in the schedule being built with little consideration of construction and production issues. This problem has long been recognized by those involved in field construction. Recent work by [Fisher and Aalami (1997)] utilized integration mechanisms called "computer-interpretable models" for the representation of construction methods and automated generation of schedules. Work by Tommelein (see e.g. Tommelein and Chua, 1998) using discrete event simulation gives an excellent explanation of how inadequate schedules arise and the problems they cause for specialty contractor performance. Time-space conflicts are another example of inadequate scheduling causing loss of production (see e.g. Riley and Sanvido, 1995; Thabet and Beliveau, 1993).

This paper will explore schedule generation in the construction industry with an emphasis on how and when schedules are produced. Using virtual construction an alternative approach to schedule generation will then be proposed linking together several existing technologies. The approach if adequately developed has the potential to change the way schedules are used by the industry, by allowing construction process design to be undertaken in earlier phases of the construction project. This will allow for designing, evaluating and testing the construction method and the schedule before field execution.

2 Current schedule generation processes

In current practice, construction schedules (baseline schedules) are usually generated during the pre-mobilization phase, Figure 1. During this stage, and based on an understanding of the design documents, including design drawings (2D) and/or CAD models (3D) of the facility, the scheduler determines a list of activities required to construct the project. Using common knowledge of construction methods and based on available resources, the scheduler creates sequential relationships among the activities and calculates activity and project duration to generate the schedule. Once construction starts, the person responsible for maintaining the schedule performs schedule updating and develops short interval schedules. In many cases, tasks involving schedule maintenance and/or detailed Short-Interval schedules generation are performed by project personnel other than the original scheduler. Schedule generation is mainly dependent on the scheduler's interpretation of the contract documents including 2D drawings and/or 3D CAD and manually translating such interpretation into a list of activities. These activities are manually linked together through knowledge of construction methods and crew availability. This process of translating the visual understanding of the project documents into a schedule is time consuming and may lead to schedule errors.

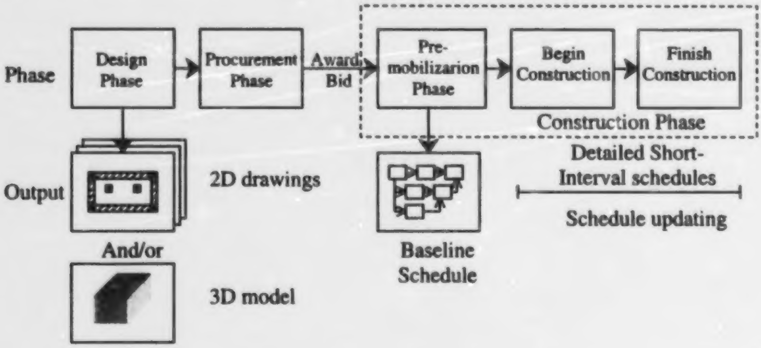

Fig. 1: Schedule generation during pre-construction phase

Several major disadvantages exist in the current practice of schedule generation. Schedule generation is only thought of during the pre-construction phase as well as the construction phase with no serious consideration to its generation during the design phase. Developing a detailed understanding of how the project may be built through the development of a schedule during the design phase will allow for a more constructable design.

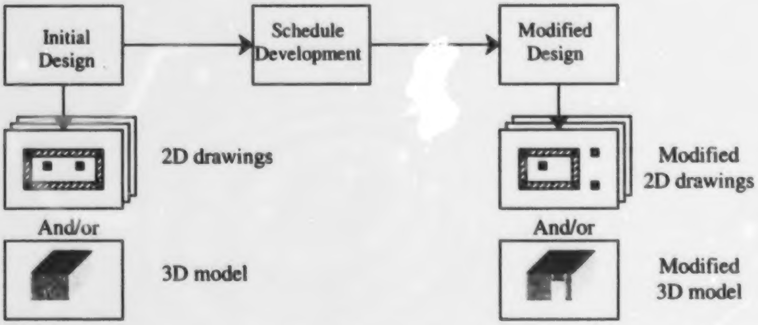

Fig. 2: Schedule generation during design phase

3 Activity generation and sequencing using virtual construction

The proposed scheduling process involves utilizing virtual construction for automatic generation of project activities and their sequential relationships. As depicted in Figure 3, using a preliminary 3D CAD model of the facility, the user can manually construct the project by re-assembling the 3D graphical elements in the virtual construction window in the perceived order of construction. The user can click and drag a graphical element, or a group of elements, from the 3D CAD model window and places it into the virtual window.

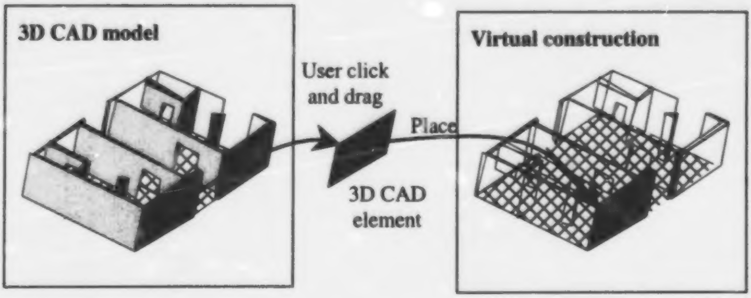

Fig. 3: The virtual construction generation process

To generate activities of the project, the user will select one or more graphical elements. Each graphical element or group of elements will represent an activity in the project activity list. The sequence of dragging the selected graphical elements will allow for creating the relationship among the activities. The relationship between the activities requires further specification. It will be possible for the user to specify concurrency, lags, and other relationships between activities in the virtual construction process.

As depicted in Figure 4, modules defining knowledge about resources, space and construction methods will help guide the user in constructing the schedule during the virtual construction session. The virtual construction system will utilize a Petri Net based tool (Wakefield and Sears 1997) to record information developed during the virtual session. Information recorded will include construction methods selected, resource utilization, and space decisions made. This will allow for carrying further checks on resources, space and construction methods following the virtual session.

By performing scheduling generation during the design stage, the developed system will enable designers and constructors to consider and tackle construction issues earlier in the project life, hence, improving design and enhancing productivity in the field. Constructors will also be able to undertake rehearsals of the construction process allowing them to analyze and compare different construction methods. This should improve on-site performance and result in better utilization of resources.

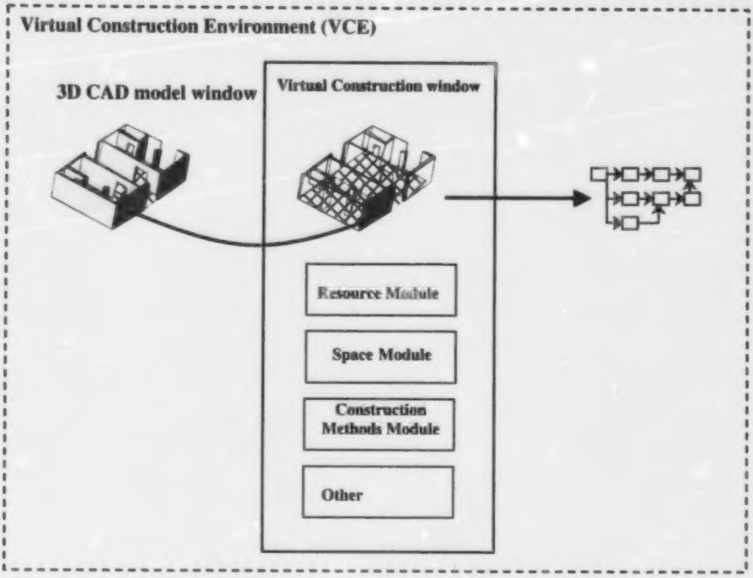
Virtual Construction Environment (VCE)
3D CAD model window
Virtual Construction window
Resource Module
Space Module
Construction Methods Module
Other

Fig. 4: The proposed VCE model

By performing scheduling generation during the design stage, the developed system will enable designers and constructors to consider and tackle construction issues earlier in the project life, hence, improving design and enhancing productivity in the field. Constructors will also be able to undertake rehearsals of the construction process allowing them to analyze and compare different construction methods. This should improve on-site performance and result in better utilization of resources.

The research ideas proposed in this paper are part of a larger research effort being developed at Virginia Tech to investigate and reconsider the planning process during preconstruction (design/procurement phases). The objective of the research work is to provide a mechanism to assist the project team in depicting construction barriers and problems that can arise during the construction phase. A Virtual Construction Environment (VCE) model is (currently at an initial stage) is being implemented to test and support the research objectives.

4 Conclusion

During the construction of a project, the constructor faces many problems that severely limit the construction performance. The depiction of these problems during early phases would tremendously reduce the cost and the duration of the project.

A Virtual Construction Environment (VCE) approach is proposed to help the project team in developing a better understanding of the project prior to actual construction.

1. Using a 3D-CAD model and a knowledge base of construction means and methods, the project team can construct the project virtually. Designers during the design phase, as well as constructors during the procurement phase, will be able to test various construction methods to virtually build the project. This will allow for predicting constructability problems that could arise during the real execution of the project.
2. Using virtual construction sessions will allow for capturing and recording user input about selected construction means and methods for automatic generation of project schedules.

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281 VIRTUAL REALITY AS A DESIGN AND VISUALISATION TOOL IN THE HOUSEBUILDING INDUSTRY

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Abstract

Improving the quality of residential design is currently a research focus in Britain. However, little work has been done on the strategic use of IT to promote innovation in the British housebuilding industry. Advanced computer techniques can greatly facilitate the visualisation and appraisal of alternative design. The potential of virtual reality as a design and visualisation tool warrants consideration. Drawing on development work and an industrial survey of British house builders, a framework for the implementation of virtual reality is developed. This is discussed within the context of the house building process and housing developers' current use of IT for design and visualisation.

Keywords: virtual reality, house building, innovation, design generation, visualisation, computer-aided design

1 Introduction

The quality of British housebuilding is poor in comparison with other countries (Gann, 1996). Innovation has become the focus of academic research (Asibong and Barlow, 1998; Ball, 1999; Gann, 1996) and government initiatives (Egan, 1998). In order to be effective, innovative strategies must be supported by appropriate IT strategies (Watts *et al.*, 1998). Despite this, the role of IT as a facilitator of innovation has not been considered by previous research on housebuilding.

Advances in computer hardware mean that real-time 3D graphics applications, previously restricted to high end computers, can now be used on PCs, and such

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applications could be of great use to housing developers in the generation and visualisation of alternative designs. The traditional methods of housing production, and the typical cul-de-sac street layouts used in Britain will be unable to provide for all the patterns of dwelling required by future demographic and lifestyle changes (Asibong and Barlow, 1998). Demanding environmental and planning considerations will make the ability to visualize and evaluate proposed developments before construction increasingly important.

Research into the potential use of PC based virtual reality (VR) systems in housebuilding organizations is being conducted at Loughborough University. As part of this research, development work was conducted in collaboration with a housing developer (Whyte *et al.* 1998a), and technical issues relating to the generation of VR models for house builders (Whyte *et al.* 1998b) have been studied. This work has been supplemented by research into current CAD and IT use within the housebuilding industry and is being followed by an evaluation of the implementation of a VR system in a housebuilding organization.

The question addressed in this paper is whether British housebuilding companies can use VR as a design and visualization tool to effectively promote innovation within their organizations.

2 Characteristics of VR Technology

2.1 VR Systems

Virtual reality, which developed out of advanced work on military flight simulators and computer graphics, has now found application in fields as diverse as entertainment, medical research, marketing and architectural engineering (Watts, 1998). The latest generations of PCs and graphics boards are making the real-time 3D graphics that once required expensive specialist computer equipment possible on the desktop.

Popular computer-aided drawing (CAD) tools now offer 3D modeling and rendering capabilities at a relatively low cost on the PC. Interactive real-time 3D (or VR) is the next step, and it could be used for the visualisation and evaluation of design before construction. In addition to commercial VR packages, an international standard for 3D models, Virtual Reality Modeling Language (VRML), has been developed (VRML'97 - ISO/IEC 14772). This standard, which is not as ambitious as the STEP and IFC standards (Wix, 1997), deals only with the description of 3D geometry and simple behaviors. In itself VRML is limited, it does not provide a mechanism for the encapsulation of domain specific information, and is a simple text description comparable to the dxf format used by CAD packages. VRML is of interest to construction industry users, however, not only because VRML models can be viewed directly, but also as CAD packages such as Microstation, modeling applications such as 3D Studio, and proprietary VR applications such as Superscape now export directly to it.

The use of VR has been compared to CAD, animation/multimedia, hand-made physical prototypes and machine-made physical prototypes. Watts *et al.* (1998) characterize VR as having high realism, high interactivity and low marginal cost, in comparison with these other technologies. This may be the overall or ideal situation but due to limitations of the current hardware, as Table 1 shows, different types of VR vary in the degree to which they show these characteristics. On the PC, despite the increased potential for 3D graphic applications, there is still a trade off between the realism of a VR simulation and it's interactivity and speed.

Table 1: Characteristics of VR

Type of VR	Marginal Cost	Realism	Interactivity and Speed
Overall	LOW	HIGH	HIGH
VR Laboratory (SGIs peripherals)	HIGH	HIGH	HIGH
PC-based VR (speed important)	LOW	LOW	HIGH
PC-based VR (realism important)	LOW	HIGH	LOW

2.2 Optimization of VR models and data translation

Thus due to hardware limitations, attainment of realistic real-time interaction, which has been of critical importance to the developers of virtual reality, involves a trade off between the accurate portrayal of geometric and architectural information and the interactivity and speed at which the VR model can be run. In order to achieve frame rates of between 5 and 30 fps, VR models are optimized, through the use of primitive solids, billboards, distant dependant levels of detail (LODs), and selective loading (Whyte *et al.*, 1998b).

Complex and highly detailed CAD data, common in the construction industry, translate into excessively large VR models. Whilst accuracy is important for architectural visualisation, and models cannot be optimized to the levels used in computer games, some optimization is required so that user movement is not unacceptably slow. Housing developers currently wishing to exploit VR technology need to consider techniques for the translation and optimization of data derived from CAD. Although it is possible for them to model residential developments completely within VR packages, such islands of automation have been shown to be ineffective (Hazlehurst, 1995). An integrated use of virtual reality, with transfer of geometrical data from, or better, exchange of data with, CAD is desirable to avoid repetitive work.

2.3 Practical modeling approaches

Three different methods for the rapid generation of virtual reality models have previously been described (Whyte *et al.*, 1998b). These are the library-based, translation and database approaches.

- **Libraries of components**, archived for reuse within the VR environment, eliminate the need for repetitive data transfer and optimization of common parts, although significant time and effort is initially required to build up the library.
- **Straightforward translation and optimization** is appropriate for the generation of one-off VR models, for example when the design process is completed and the design is fixed and unchanging.
- **A database approach**, though not yet commercially implemented, describes the creation of a central building product model database, from which the building can be viewed through VR, as well as a range of other applications such as CAD. Such an approach would be suitable for rapid prototyping where optimization of the model for real-time viewing is not critical.

A series of customizable filters could help to automate the translation and optimization process, providing options for the reduction of geometrical information, the rendering and addition of behaviors to the resultant model. The substitution of pre-optimized geometries from a library of building objects could be an option during such a translation process.

3 Matching IT strategies and house building processes

3.1 IT and innovative housebuilding organizations

The interface between construction processes and IT support is discussed by Aouad *et al.* (1998) who describe a synchronized process/IT model for the co-maturation of process and IT and the strategic management of change. According to this approach IT introduction and application should be designed to suit the existing process capability, and a balanced profile of maturity is favored, even if this maturity is low. The nature of housebuilding processes and IT use within the housebuilding industry have been investigated in order to draw conclusions about the potential implementation of VR technology.

VR use helps to develop three features common to many leading innovative organizations. These features are a capacity to experiment in depth, involvement of all in the innovation process and an ability to capture ideas generated in the innovation process (Watts *et al.*, 1998). The relation of these features to housebuilding is shown in Table 2. American research into the adoption of technological innovations (Toole, 1998) has found that house builders who are more apt to adopt nondiffused technological innovations tap into more sources of information about the new products from portions of their organizational environments than do nonadopters. Communication of information across job functions within organizations seems to be important in the adoption of innovation.

Table 2: How VR use can help the British housebuilding industry to attain the characteristics of innovative organizations

Characteristics of innovative organizations	How VR use can help in housebuilding
Capacity to experiment in-depth	• PC-based VR is of relatively low-cost and hence provides a low-risk environment in which initial prototyping of innovative house designs can be tried. • Rigorous prototyping of new housetypes can take place to avoid costly failures.
Involvement of all in the innovation process	• Marketing staff and management are often unable to read drawings; the high realism of VR allows non-technical staff to contribute expertise to the design process. • Communication of information across job functions facilitates innovation.
Ability to capture ideas generated in the innovation process	• Need to change to improve the quality of housing and the type of houses built

3.2 The housebuilding sector

The British housebuilding industry is relatively small and fragmented, with the leading housing developer producing 14, 000 houses a year, and only 143 housing developers producing more than 100 houses in 1997 (NHBC, 1998). The regulatory and institutional framework and the structure of the industry are different from the Japanese housebuilding industry where production is factory based and the industry is more cooperative and vertically integrated with the housing developer in control of the supply chain. In Britain, construction is traditionally brick and block and it is sub-contracted to take place on site, the tendering process encourages secrecy and design of elements such as kitchens are carried out in the design chain.

Although the organizational structure of the large house building company varies from one developer to another, the typical house builder involved in speculative development can be seen as having a central office in which most of the house type design work is undertaken. Several regional offices then co-ordinate sites in their area, and are involved in site layout design and consultation with local planning officers, liasing with the on-site sales offices which market the finished products (Gillen, 1994).

Ranges of standard house types are used by most of the national house builders (Nicol, 1999). Facades are modified to meet planning requirements in different regions, but housing developers are reluctant to undertake structural changes, which require re-application for National House Building Council (NHBC) approval, and are unable to offer extensive customer customization. As land prices and management of a landbank have been critical strategic considerations for speculative developers there has been little investment in design and innovation is slow (Ball, 1999). However this may change (Asibong and Barlow, 1998) as government initiatives and comparison with the manufacturing industry has led to proposed changes in housing developers operational procedures (Gann, 1997).

3.3 Computer use for design within British house building

In the industry survey undertaken (Whyte, 1998) it was found that computers are used in the British housebuilding industry for design much more widely today than they were in the late 1980's. Seventy four per cent of the housing developers that replied to the survey had some CAD in-house. There was a wide range of CAD use within the industry however, with some housing developers having less than 10% CAD use whilst others reported over 90% CAD use. Whilst some housing developers are new to CAD, several of the larger housebuilding organizations had over a decade experience in using CAD. Unlike in the late 1980's (Ewin *et al*., 1990), today there are software companies specialized in producing software for the housebuilding market.

In many of the early CAD packages it was easier to redraw a feature than to try to alter it, and many of the housing developers interviewed described the kind of procedures necessary to get round problems with such software. The ability to alter a drawing is important to the housing developer, as it is rare that a housing design is started from scratch, instead existing housing designs are continuously altered and updated. One housing developer demonstrated the features of their current CAD system, Speedikon, which facilitate drawing alteration. There were a series of view filters that can be used to view different sets of data, and search-and-show capabilities: attributes can be searched for and then changed *en masse*. For example changes can be made to all types of door.

Industrial standards are not widely used in the housebuilding industry, and many companies have difficulty implementing company-wide standards. The BS layering standard is seen as unnecessarily complex and those housing developers that use it have software that defaults to these standards, others that have implemented in-house standardization have favored about 10 different layers. The CAD manager from one housing developer explained they tried introducing protocols for the use of CAD, but found this to be restrictive. Ultimately they hope to have a standardized system but hope that this will come about in a bottom up way, rather than being imposed from above.

3.4 Attitudes to VR in the British housebuilding industry

Interviews with housing developers that followed VR development work, shown in Figure 1, revealed that the realism of VR was seen as most useful for visualisation of design ideas by non-technical personnel (Whyte, 1998). Designers felt comfortable reading abstract 2D design information, whilst non-technical staff, such as marketing and sales staff, and external parties, such as customers and planners benefited from VR visualizations in order to input their particular expertise into the design process.

In relation to housetype design, some housing developers mentioned the low cost of VR in comparison with their current practice of producing physical prototypes of new house type designs for in-house appraisal. Although the justification of VR use sought in this inquiry is based upon its potential to facilitate innovation, rather than to cut costs, the low cost of VR encourages experimentation.

Fig. 1: A demonstration project shows the potential of VR for the visualisation of design ideas by non-technical staff

4 A Framework for the implementation of VR

A housing developer hoping to utilize VR technology has some decisions to make with regard to implementation. The kind of implementation strategy used is dependent upon the requirements made of the VR system and the process it supports. Different housebuilding activities make different requirements of the VR system as shown in Table 3. For example, the use of VR for presentation to clients requires a high level of realism, but this can be achieved by texture mapping a simple geometric model rather than creating a complex model. For detailed design and prototyping, more geometric information is required, but there is less need for photographic realism. As designers are better able to read abstract information, even less realism may be required at the early design stage.

The use of VRML or commercial VR systems would be useful at all stages of the housebuilding process, but different strategies are more appropriate to the different tasks. Translation and optimisation strategies need to be carefully considered in relation to the geometric accuracy, realism and interactivity required and the necessity of data transfer to and from CAD.

Table 3: VR characteristics required for different housebuilding activities

VR use	Geometric Accuracy required	Realism required	Interactivity	Data Transfer to/from CAD
Early Design	Medium	Low	High	Rapid transfer important
Detailed Design and Prototyping	High	Medium	Medium	Some transfer
Visualisation in-house	Medium	Medium	Medium	Some transfer
Presentation (to clients, planners etc)	Low	High	Low	One way transfer from CAD adequate

To support innovation the maturity of the IT strategy should be matched to that of the maturity of the process strategy. In an industry such as housebuilding where processes are undergoing scrutiny, the implementation of a VR system must suit current practice, but not be rigidly dependent on it.

5 Conclusions

British housebuilding companies need to build on their current computer use by investing in appropriate IT strategies to support innovation, in order to improve building and design quality, to respond to consumer needs and increase their competitive edge.

The use of PC based virtual reality as a design and visualisation tool can be used to promote innovation, and it has certain advantageous characteristics. Virtual reality allows experimentation in depth, involvement of both designers and non-technical staff in the innovation process and ideas generated in this process to be captured. These characteristics of VR can be used to facilitate innovation within house building organizations.

Introduction of VR ought to suit existing process and IT capability and an appropriate VR package is likely to share data with CAD and have an ability to support interactive viewing and change. The successful implementation of VR in related sectors and within housebuilding in other countries suggests that VR will be useful to housebuilders in Britain, but such experiences cannot be applied uncritically.

Large house builders with high levels of CAD use and experience, who invest in design, ies will be most able to harness the benefits of VR technology. Such progressive housebuilding companies will be able to use this technology to improve organizational efficiency and enhance their innovative potential.

6 Future Work

Research into the implementation of a VR system within a housebuilding organization is currently being undertaken. The theoretical principles developed in this paper will thus be tested against a real example where VR software is being implemented for use within the design process in a number of regional offices of a housebuilding organization.

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